COMBUSTION

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Mechanical Stoking for Ships' Boilers
By S. McEWEN

Power Stations in Paris
By DAVID BROWNLIE

Other Articles in This Issue By
F. L. GILMORE • G. A. ORROK • WM. L. DeBAUFRE • JOSEPH BRESLOVE • A. L. BROWN • B. J. CROSS

COMBUSTION

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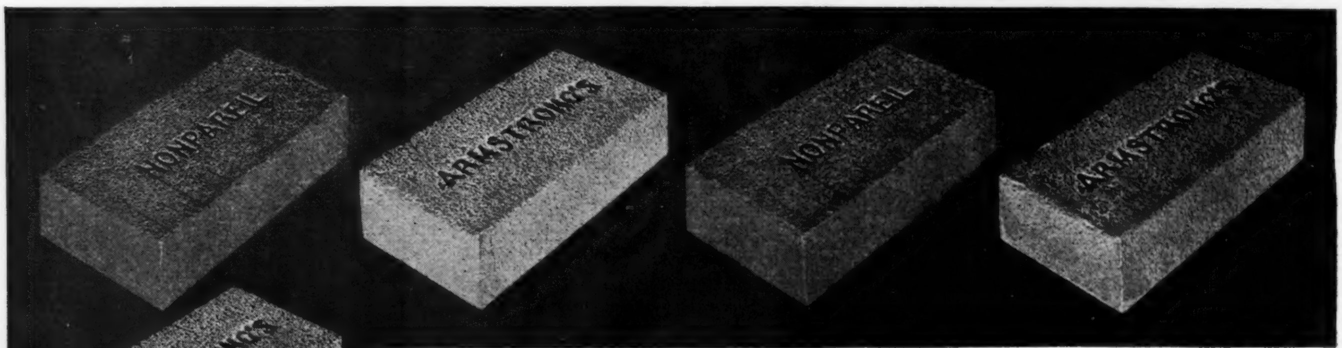

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The Need of Research In Welding

H. F. MOORE

FROM the earliest days of the study of the theory of heat engines, it has been recognized that increase in efficiency of transformation of heat energy to mechanical energy demanded as high a maximum temperature as practicable. The practical limitation of efficiency of heat engines has always been due to the strength limitations of available metals at high temperatures. Any discovery in metallurgy or the art of metal fabrication which gives us metal parts, capable of withstanding higher temperatures than have hitherto been possible, is of prime importance in the economical development of power from fuel of any kind.

Of recent years, there have been marked advances in metallurgy in the direction of heat-resisting metals. Today, metal parts are working successfully at temperatures as high as 1000 deg. fahr., and there is the possibility that this figure may be substantially increased in the near future. But in making pipes, tubes, and boiler shells it is necessary either to make a very expensive forging or to fasten pieces of metal together, and usually the weak point of a pressure vessel is found in the joints, be they riveted joints or welded joints. The development of fusion welding gives promise that in the near future we may hope that this weak part of pressure vessels may be made, like the weakest part of the "one hoss shay," "as strong as the rest."

However, 100 per cent welded joints are by no means common in general practice today, and no field of metal research offers larger practical returns than the study of the making, heat treating, forging, and testing of welded joints in pressure vessels.

One problem calling loudly for solution is the development of a *non-destructive* test which shall enable the observer to detect minute flaws in a welded joint,—the kind of a test which can be applied to a joint in a structure, a machine part, or a pressure vessel. Direct examination by X-rays (or by Gamma rays) has given promising results in several cases, and there may be developed a practical X-ray method for detecting internal flaws of a magnitude which would be visible to the naked eye were the defects at the surface. The Sperry method of locating small flaws by measuring the change in electrical resistance has been used successfully for detecting flaws in rails and is being tried out for detecting flaws in welded joints. The Kinzel stethoscope test for flaws in welds uses inexpensive equipment but requires a rather highly trained ear, and, at present, would be subject to a rather large personal factor. None of these methods has been in use long enough to be definitely evaluated at the present time. Possibly some elaboration of the Kinzel or some other acoustic test—a glorification of the old method of tapping joints with a hammer—may meet the situation. Possibly the X-ray or the electrical resistance method may be developed so that smaller flaws can be detected and the expense of the test brought within practicable limits. But today there is great need of intensive study to develop such a non-destructive test. With such a test available, improvement in strength and reliability of fusion welded joints in pressure vessels would be greatly accelerated.

Is not this study worthy of subsidy by some group of manufacturers who use welding, or by some national foundation interested in researches in physical science?

H. F. Moore

Research Professor of Engineering Materials, University of Illinois

EDITORIAL

The Theory of Relativity—What is its Significance?

WHENEVER Science gets comfortably settled, some iconoclast always comes along and sets off a theory that stirs things up again.

The latest fireworks were labeled "Relativity".

The theory of relativity pertains to certain intricate and abstract relationships in which time and space are inseparably joined into a four dimensional entity which the finite human mind, encumbered with its three dimensional limitations, cannot comprehend, directly. Only by analysis through the medium of higher mathematics, can these relationships be defined and applied.

So long as the subject was confined to pure science, we were content. But, today it threatens to invade our engineering precepts.

Unfortunately, the theory is sadly misunderstood and its importance to mundane affairs has been grossly exaggerated by the many semi-popular expositions of the subject.

These attempts to explain the theory of relativity to the lay mind may be likened to placing a fine watch in the hands of a savage Australian bushman. The delicate parts of the watch may be correctly designed and properly coordinated into a perfect mechanism. However, the device, although fascinating, is absolutely useless to the aboriginal for he does not know how to wind it nor can he interpret the position of the hands into an expression of time.

To those who are prone to take mental excursions into the great open spaces of interstellar depths, where distances are measured by light years and where temperatures range from close to absolute zero in the voids to 50,000,000 degrees at the centers of star bodies—an understanding of the theory of relativity may be of value

If the wanderlust carries you far away from the home galaxy to those remote nebula clusters which are so distant that their light is more than 50,000,000 years in reaching us, you may find need for a four dimensional relationship, which perchance may be able to cause space through a series of mathematical gymnastics to fold back on itself just in time to avoid some grievous cosmographic error.

It may be interesting to know that energy has mass, and that, when the Mauretania is making 25 knots, her normal weight of 50,000 tons is increased, due to her energy of motion, by about a millionth part of an ounce. In calculating the speed of electrons in atomic physics, the theory of relativity finds application, but in applied engineering, within the four walls which define your office, your boiler house or your turbine room, the good old-fashioned Newtonian theories will continue to give results which, although only approximate according to the theory of relativity, will be close enough to serve all practical purposes for some time to come.

An Investment That Yields 25 Per Cent—or Better

IF securities were offered for sale which yielded 25 per cent and which were guaranteed by a reputable organization, the public response would be immediate and the issue would be heavily over-subscribed in short order.

If it could further be shown that the ownership of such securities would improve labor conditions, contribute toward civic betterment and reduce production costs throughout industry, the demand would be in the nature of a stampede.

A yield of 25 per cent, or better, on a sound investment is by no means visionary. In fact, this precise opportunity is available to thousands of industrial plant owners throughout the country.

The replacement of obsolete firing methods by modern stoker equipment will effect a reduction in fuel cost of from 10 to 20 per cent in the average industrial steam plant. This saving will probably represent a return of 25 to 50 per cent on the cost of the stoker installation and the reduction in steam cost is immediately reflected in the final cost of manufacturing the particular commodity which the plant produces.

The incidental advantages include improved working conditions, smokeless operation and greater reliability of steam and power supply.

The stoker investment is sound because stoker equipment is sold by reliable manufacturers, under positive performance guarantees which protect the purchaser and insure his investment.

The true value of an investment depends on the rate of yield—not on how the yield occurs. A reduction in the number of dollars going out is equally as important as an increase in the number coming in.

It is peculiar, however, that investments which provide for the clipping of coupons are always more alluring than those which assure far greater returns, but in the form of savings effected.

Thus, countless opportunities for stoker investments, which would yield 25 to 50 per cent, are going begging.

Mechanical Stoking for Ships' Boilers

By S. McEWEN
London, England

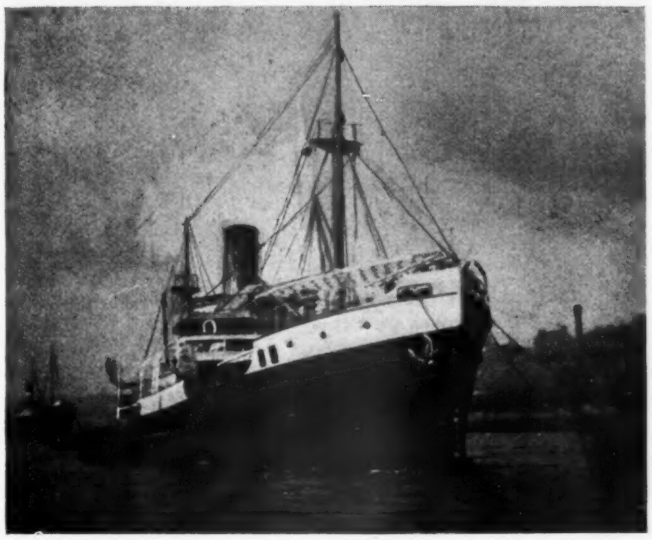


Fig. 1—S. S. Bintoehan, Koninklyke Paketvaart Maatschappy line, the first of 40 vessels of this line to be equipped with mechanical stokers

The use of mechanical stokers for firing ships' boilers is not a new development. In fact, the earlier applications date back almost to the beginning of this century. The story of this particular phase of stoker pioneering is told very interestingly in the accompanying article. Mr. McEwen has had a long and intimate identification with this development and his article represents an important contribution to the literature of the subject. Of particular interest is his analysis of the reasons for the failure of early installations which indicates that the difficulties were due very largely to the human element. Traditional customs of the sea were threatened by the adoption of stoker firing and those affected found ways and means of preserving their customs. As a result practically no real progress was made until the early part of the last decade. Since then a number of successful installations have been made. . . . Extensive adoption of stoker firing on shipboard would seem to require a degree of cooperation on the part of all concerned that is not yet generally obtainable. However, the success attained in equipping forty vessels of one line, as described by Mr. McEwen, should serve to indicate the real advantages of such applications and should result in materially accelerated progress in the modernization of coal burning practice aboard ships.

TWENTY-SIX years ago the application of mechanical stokers to steam boilers had in England progressed sufficiently far to enable mechanical stoker manufacturers to realize that the practice of hand firing was definitely doomed to gradual extinction. The benefits to be derived from mechanical firing had been established and the foundations laid for developments which probably have far exceeded in extent the most optimistic anticipations of the pioneers of this industry. At this time those pioneers who were associated in the direction of the activities of the Underfeed Stoker Co. Ltd., of London could not fail to realize what a vast scope for their future endeavors existed in the marine world, it seeming obvious that the benefits which had been proved in land practice should be realized to even a greater degree with the application of mechanical firing to ships' boilers. With complete confidence in the successful issue of the endeavor the Underfeed Stoker Co. Ltd., applied its resources, technical and financial, to secure the substitution of improved and mechanical methods for controlling combustion for the primitive and often unintelligent practices of the manual stokers.

As is so frequently, one might almost say invariably, the case when established practice in one field is transferred to another, countless difficulties presented themselves of so varied a character that their cumulative effect was beyond all that the pioneers could be reasonably expected to foresee. To-day, twenty-six years later, the record of progress is disappointing and, in fact, except for one outstanding instance, the progress may be described as negligible.

The efforts made by the pioneers are of historical interest, and the following brief survey of the work done during the five years following the initial installation in 1904 will indicate the magnitude and the earnestness of the effort, and will serve as a preface to a review of the factors which at that time rendered the efforts futile, and necessitated the temporary termination of the endeavor.

In 1904, negotiations with the owners of the Wilson line of steamships resulted in the equipment of three Scotch marine boilers of the S.S. Idaho with mechanical stokers of precisely similar type to those which had proved to be successful when applied to internally fired boilers on land. The promise of im-

proved combustion and economy in coal consumption was realized, but it soon became evident that mechanical failure of even a minor character which would have been tolerable on land assumed a serious importance on sea.

This called for a new technique, new standards of manufacture, and even necessitated a complete change in design. Shafting, pulleys, ratchets, gear wheels and other similar standard mechanical appliances had to be abandoned—moving parts had to be reduced to a minimum, and an attempt made to apply power by means familiar to marine engineers and customary in marine practice.

This was attempted and accomplished in the design known as the Class D Underfeed Stoker. The motive power for this stoker was a steam cylinder directly applied to the feeding ram and coal distributor. The general design and application of this stoker are shown in Figs. 2 and 3.

Between the years 1904 and 1906, mechanical stoker installations were made on five ships of the Wilson Line. These ships were: S.S. Idaho; S.S. Mourino; S.S. Kolpino; S.S. Toronto; S.S. Torino.

In all, thirty-nine Class D stokers were installed in addition to nine Class B stokers of the land design.

The fact that after the initial installation further ships were equipped over a period of about three years, is sufficient to prove that some material benefits were secured from mechanical firing, and it also showed that at that date ship owners and marine engineers were willing to modernize their methods and adopt improvements which would lead to increased efficiency and economy.

This willingness can best be exemplified by the rapid extension over the whole world of shipping of the use of air preheaters and forced draft. In this respect the marine engineers lead the land engineer, for it was many years before land engineers realized the advantages to be derived from forced draft and the transference of heat from the flue gases to the air required for combustion.

Throughout the year 1907, further developments in mechanical stoking on ships seemed to be checked by sinister influences. Doubts were expressed as to any actual economy being obtained over an extended period. Ships' engineers found reasons for discrediting mechanical stokers, such reasons being generally

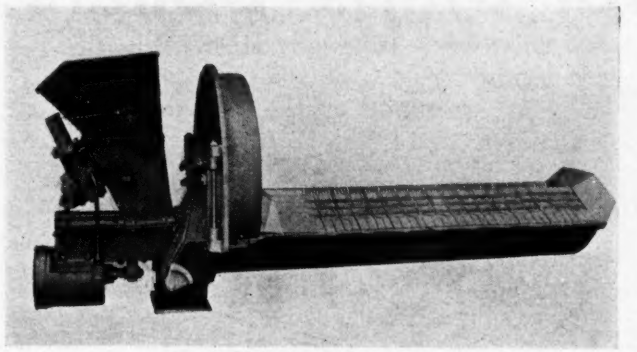


Fig. 3—Class D Underfeed Stoker for marine boilers—the first stoker developed for this service

indefinite in character but giving the impression that any economies in coal consumption were more than counterbalanced by repairs and maintenance, loss of time and extra work in port. These adverse grumbles were not supported by actual figures or data, and so far as could be determined by disinterested observation could not be justified by the facts.

In 1908, a new opportunity was secured with another line of steamships when four years of accumulated experience on land and on sea could be devoted to the rectification of any past defects and an attempt be made to establish the benefits of mechanical stoking beyond all question. In that year, the S.S. Corinthian of the Allan Line had one of its Scotch Marine Boilers fitted with three Class D stokers. The boiler was equipped with Howden's forced draft.

It was arranged that definite guarantees of performance should be given and performance was to be established by actual boiler trials, mechanical stokers vs. hand firing, conducted as in land practice,

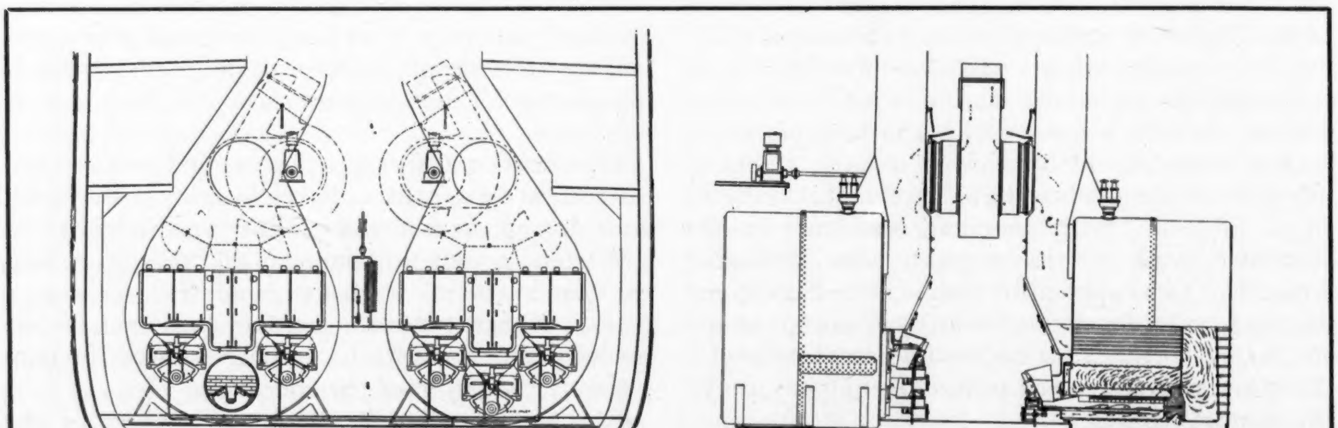


Fig. 2—Application of Class D Marine Mechanical Stoker

coal and water being weighed in the usual way. At that time, little or no heed was given by marine engineers to the individual performance of ships' boilers. Coal consumption and indicated hp. were recorded and the performance of the whole power equipment was judged by the factors established by these records.

In the first place a hand-fired trial was made, the coal used being normal bunker coal of good quality known as "Newcastle Mixed," and this established the basis of comparison. For the subsequent trials with mechanical stokers, a lower grade and cheaper coal was supplied.

The comparative results were as follows:—

Name of ship: S.S. CORINTHIAN, Allen Line.
One Scotch Marine Boiler with 3 Flues.

Name of Coal	Newcastle Mixed	Durham Unscreened
Date of Test	August 26th, 1908	October 13th, 1908
Method of Firing	Hand	Mechanical Stoker Class D
Duration of Trial	8 hours	8 hours
Grate surface	55 sq. ft.	55 sq. ft.
Water heating surface	2152 sq. ft.	2152 sq. ft.
Steam pressure	165 lb. per sq. in.	172 lb. per sq. in
Temperature of flue gases leaving boiler	707 deg. fahr.	674 deg. fahr.
Temperature of flue gases leaving air heater	482 deg. fahr.	450 deg. fahr.
Temperature of feed water	198 deg. fahr.	173 deg. fahr.
Temperature of steam	365 deg. fahr.	369 deg. fahr.
Total weight of coal consumed	11,368 lb.	13,760 lb.
Total weight of ashes removed	1,307 lb.	1,490 lb.
Weight of ashes—per cent	11.5	10.8
Weight of fuel burned per hour	1,421 lb.	1,720 lb.
Fuel burned per sq. ft. of grate	25.8 lb.	31.27 lb.
Percentage of CO_2 in flue gases	9.4	10.5
Total weight of water evaporated actual	96,628 lb.	130,857 lb.
Factor of evaporation	1.068	1.09
Total evaporation from and at 212 deg. fahr.	103,247 lb.	142,634 lb.
Water evaporated per hour actual	12,078 lb.	16,357 lb.
Water evaporated from and at 212 deg. fahr.	12,905 lb.	17,829 lb.
Water evaporated actual per lb. of coal	8.5 lb.	9.51 lb.
Water evaporated from and at 212 deg. fahr., per lb. of coal	9.08	10.36
B.t.u. in coal as used	13,741	12,303
Efficiency	63.8 per cent	81.38 per cent

The comparative trials proved that by stoker firing an increased capacity of 38 per cent could be obtained from the boiler, while the efficiency was increased from 63.8 to 81.38 per cent, these results being secured although the trial with mechanical firing was with a cheaper fuel.

It is admitted that the hand-fired trial showed extremely poor results and that, given skillful firing, the results would have been much better. It is known in fact that in the practice of the Royal Navy of twenty-eight years ago efficiencies could be obtained by hand firing equal to the best mechanical firing; this, however, involved the firing of weighed charges of coal at regular intervals and distributed according to a firing chart, the fire doors being opened and closed by an additional man with machine-like precision. In the mercantile marine, however, the firemen cannot be drilled to this extent; the personnel of the stokehold is usually not permanent and is of a type classed as casual and unskilled.

In the case of the S.S. Corinthian the hand-fired test was supposed to be conducted under normal conditions, but the engineers, not being satisfied that justice was done to their boilers by the results obtained, carried out other hand-firing trials and succeeded, still using the good quality coal, in obtaining an efficiency of seventy per cent, as compared with 81.3 per cent obtained on the stoker fired boiler.

It was claimed for the mechanical stokers, however, that a high average efficiency would be maintained regardless of the skill of the firemen, and that the benefits from their adoption would in large part arise from the lack of skill which must be expected from sea-going manual stokers.

The economy due to improved combustion and from the use of a cheaper coal combined to show such a considerable saving in fuel costs as to warrant the anticipation that the equipment of the remaining boilers on the ship with mechanical stokers would be undertaken and that other ships of the Line would be similarly converted. During several of the sailings of the S.S. Corinthian between England and Canada, a combustion engineer representing the stoker company sailed with the ship to take observations and to assure that the initial satisfactory operation could be maintained in regular service.

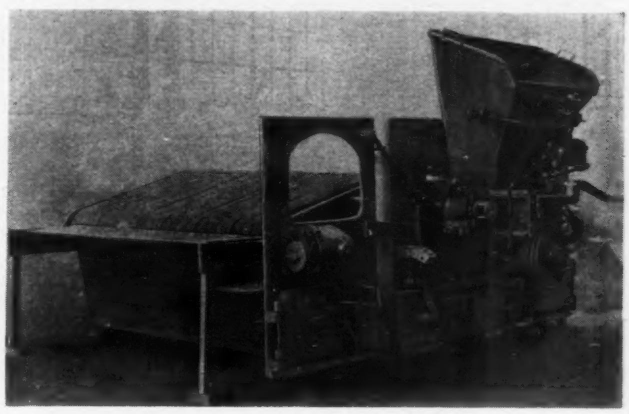


Fig. 4—Class E Underfeed Stoker for marine water tube boilers

In spite, however, of every promise of success, hopes of rapid extension of the adoption of mechanical firing assumed a less confident character after several sailings had been made without the supervision of the combustion engineer. As in the case of previous ships, murmurs of complaint of indefinite character were heard and in a surprisingly short time the stokers were dumped on the wharf and grates for hand firing replaced them.

One further attempt in 1908 was made by equipping a Scotch marine boiler of a newly built ship—the S.S. Paris, but in this case circumstances necessitated the use of a semi-bituminous bunker coal which was unsuited for mechanical firing in a boiler of the internally fired type.

Up to this time, over a period of five years, mechanical firing had been applied on seven ships and

in all forty-five mechanical stokers had been fitted to ships' boilers.

The persistent and costly effort having so far resulted in failure, it was necessary to make a careful review of the whole of the experience gained in order to determine whether the effort should be continued on somewhat different lines which would have to be determined, or whether it should be entirely abandoned. Adopting a process of elimination it is possible to say that failure could not be ascribed to:

Indifference of the owners to economy.

Lack of skill on the part of the marine engineer as compared with the land engineer.

The inability of mechanical stokers to secure the improved average combustion and fuel economy on board ship which had been established in land practice.

For an explanation it was necessary to investigate the cause for the indefinite complaints which shrouded the whole endeavor and which made mechanical stokers so unpopular on board ship that in every case sooner or later they were jettisoned. Individually, the complaints and the considerations which prompted them seemed trifling, but collectively they were sufficiently formidable to cause the cessation for many years of any further activity. The following is a summary of the factors which were held to be responsible for the lack of success.

Fig. 5—Installation of Class E Stoker aboard ship

In the matter of purchase of bunker coal there existed certain privileges and the use of a cheaper coal and a threatened reduction in quantity adversely affected those associated with shipping who were interested in the privileges referred to. Moreover, it was generally understood that a discrepancy between the actual weight of coal delivered and that which was registered as delivered was by no means uncommon. Coal saving as reported by bunker purchases might not confirm the saving established by boiler trials.

Bunker coal might be delivered in lump form at a foreign port unsuitable for use in mechanical stokers; the firemen would have to break it by hand and if this were not done effectively a large lump in a stoker hopper could choke the machine with results that would call forth invective from the whole of the ship's personnel from the Captain down to and including the delinquent fireman.

The ships' firemen were not permanent employees, they were frequently changed at each port of call and, on occasions, would present themselves for duty in a condition which was unfavorable for the reception of instruction on the subject of mechanical firing. Men taught the proper method of operation would leave and the engineer on watch in the boiler house had to be a permanent instructor or do the work himself. The engineer on watch developed a distaste for high efficiency combustion and everything associated with it.

Repairs had to be executed in port; mechanical stokers required some repairs and these were inevitably a little more complex than the replacement of a few grate bars on hand-fired grates. Certain of the engineers could not leave the ship in port to visit their friends and families till repairs were executed and thus it frequently happened that leave was curtailed, or repairs improperly executed. In the former case, the engineers responsible would anathematize the stokers and, in the latter, the ship would sail with a defectively repaired machine which might fail in mid-ocean—an occurrence which would effectively seal the fate of the mechanical appliance.

The Captain had been known to complain that owing to the absence of smoke from the funnel he was unable to see the way the wind was blowing.

A review of all these conditions disclosed circumstances beyond the power of a single but earnest company to combat, and there appeared to be no alternative but to wait until the march of industrial progress could insure more favorable conditions.

For a period of eleven years no further attempt was made in marine work by the Underfeed Stoker Co. Ltd., and uneconomic and inefficient hand firing persisted until the introduction of oil fuel threatened to secure the desirable efficiency in an effective way in virtue of its ability to break down all the old barriers by dispensing with the old bunkering system, the manual labor of the stokehold, and the necessity for mechanical repairs.

In 1920, the writer of this article was approached by Mr. Muller, Superintendent of the Koninklyke Paketvaart Maatschappy, who had fully investigated oil firing and ships' propulsion by Diesel engines, and as a result was disposed to favor the use of coal fired mechanically. The whole of the past experience of the Underfeed Stoker Co. Ltd., was frankly recounted to Mr. Muller who, with a directness which is characteristic of him, said that he was prepared to provide conditions which would eliminate completely all those objectionable factors which had balked our progress in past years.

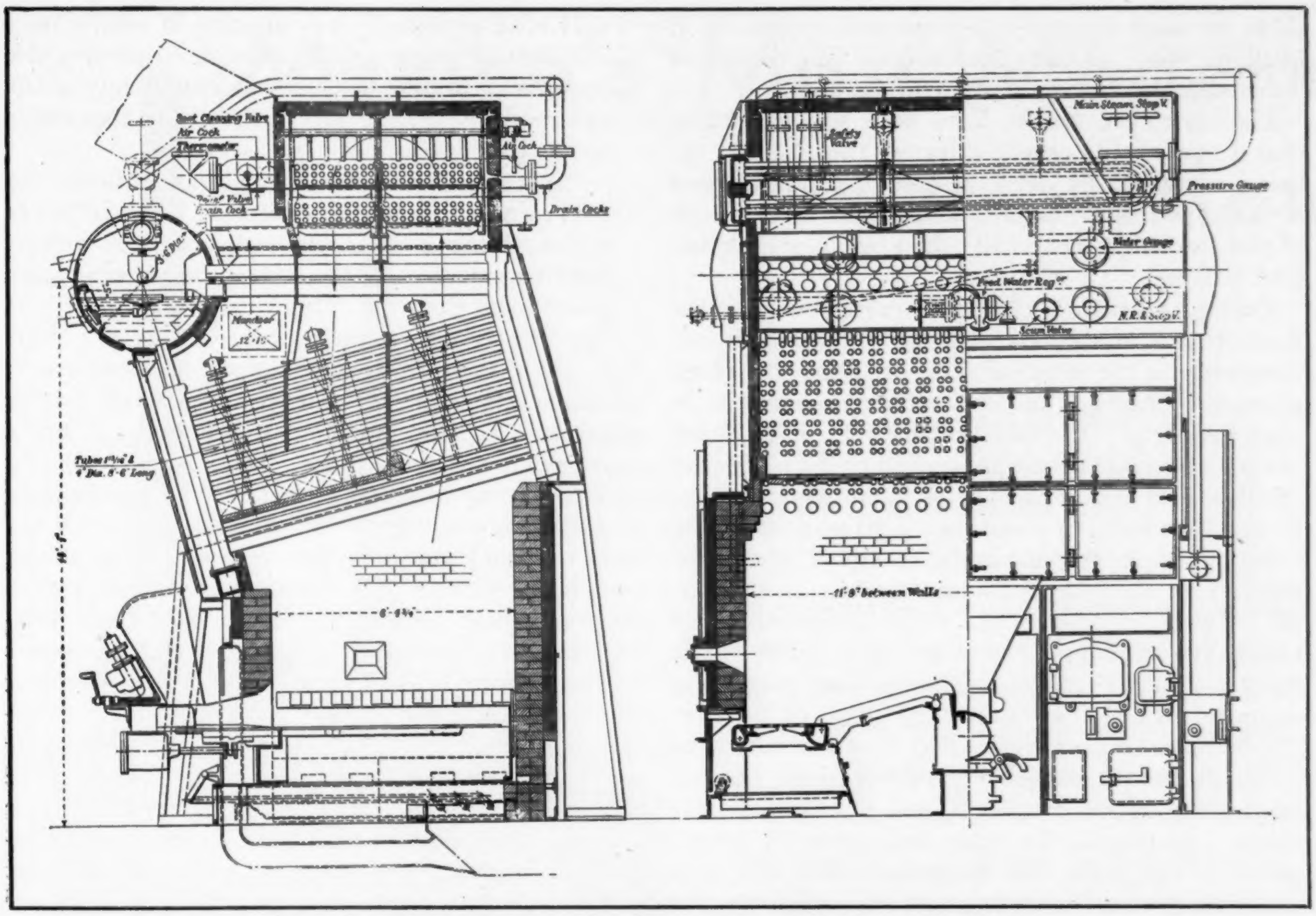


Fig. 6—General arrangement of installation of Class E Stoker on the S.S. Patras

Mr. Muller undertook to fit a Class E Underfeed Stoker to a water tube boiler in a new ship and the following conditions would be established.

The coal for combustion would be exclusively obtained from the company's own collieries and would be uniform in quality and consistently suitable as to size.

The stokehold or boiler room would be controlled as a land boiler house, weighing, measuring and recording apparatus would be installed and the whole would be in the charge of technically educated engineers. The stoker attendants would be unskilled but permanently engaged men who, once instructed, could be relied upon to carry out their appointed duties.

Mr. Muller asked that the Underfeed Stoker Company should, for its part, make such modifications to the standard Class E Stoker with regard to materials and detailed design as would make it conform with the best marine engineering practice. This cooperation resulted in what may be indubitably claimed to be the first complete and induring success secured at sea for mechanical firing.

Starting with the S.S. Bintoehan, a Class E Underfeed Stoker was fitted to a Babcock & Wilcox marine water tube boiler. Figs. 4, 5 and 6 show this stoker and its mode of application to marine watertube boilers.

The stoker fired S.S. Bintoehan was a new ship and it passed its trials satisfactorily and proceeded into regular service in the Dutch East Indies. During the trials it was noted that the funnel temperature was higher than was reasonable considering the relation between heating surface provided and the quantity of coal consumed; it was further noted that some unburnt gases were passing to the stack. Up to this time it had been customary, in conformity with the general practice in naval architecture, to set the water tube marine boilers very low, limiting the size of the combustion chamber to an absurd degree. This practice limited the fuel which could be efficiently burned to a semi-bituminous smokeless Welsh coal. As the trials of the S.S. Bintoehan were conducted with a high volatile bituminous coal, the small combustion chamber was obviously unsuitable. In this matter Mr. Muller again took a decision which indicates the spirit in which he approached the problem of mechanical firing for ships' boilers. He immediately arranged that the next ship under construction, the S.S. Parigi, should have its boilers raised, thereby materially increasing the volume of the combustion chamber; he insisted that the ship's architects should modify their construction to conform with this alteration.

The S.S. Parigi on her trials showed a very satisfactory reduction in the flue gas losses which fully warranted the change in setting.

The earlier results and experiences with these two

ships are fully reported in a paper read by Mr. W. J. Muller, M.E., (Delft), before the Institution of Naval Architects, September 5th, 1923.

The continued results have been so satisfactory that some of the latest ships of the K.P.M. are being mechanically fired, and to date, nine years after the preliminary trials, no less than forty vessels of this line are mechanically fired by Class E Underfeed Stokers.

During this period, there was another stage in the development of mechanical firing at sea which was constantly in the minds of those studying this phase of marine practice, and this related to mechanical coal handling. In land practice, the main labor saving advantage of mechanically firing a number of small boilers as compared with hand-firing was due to the possibility of utilizing mechanical coal handling plant to automatically transport coal from bunkers to the hoppers of the mechanical stokers. Mr. Muller, in cooperation with Underfeed Stoker Company, attempted to solve this problem for marine practice and a coal handling plant was actually installed on one of the ships of his line. The arrangement was necessarily complicated owing to shape and disposition of ships' bunkers, the confined space of the stokehold and the lack of head room. Although the plant was operated over a period of two years, this equipment had finally to be abandoned. Coal trimming was still necessary, the additional plant and machinery required attention and no net saving was effected.

Mr. Muller's experience in his search for fuel economy over a period of eight years was recounted in a paper read by him before The Institute of Fuel, October 23rd, 1930. The following is an extract from that paper:—

"The principal improvement, however, was the application of the underfeed mechanical stoker, by which means not only the efficiency was raised to 75 per cent (and even to 78 per cent with superheated steam), but which also made the company practically independent of the skill of the firemen, so that unskilled labor could be employed. Moreover, it became possible to burn cheap and also very small coal, containing a high percentage of ash (30 to 40 per cent), which fuel could now be used economically for ships running in certain services, and which had been impossible hitherto with hand fired cylindrical and watertube boilers. The principal merits of the mechanical stoker of the underfeed type are, in the first place, suitability for burning high volatile coal because of the central retort or coking chamber in which the coal is degasified before it is deposited on the sloping grates at the sides, on which the remaining coke is burnt out; and in the second place, the simple and very effective way in which the ash and clinker are removed from the grates by means of dumping trays, placed at the sides of each sloping grate. Thirdly, the underfeed stoker can deal with practically any amount of ash, if only the melting point is high enough to prevent the forming of big clinkers, which fortunately is the case with the greater part of the native coal found in the East Indies.

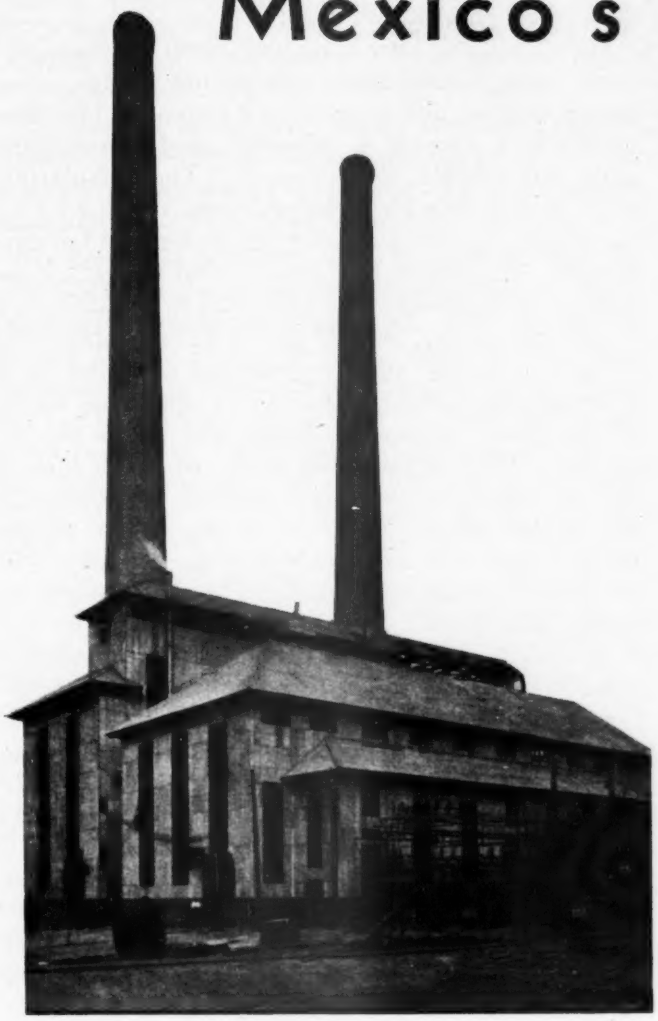
"In comparison with the cylindrical boiler the coal consumption of the watertube boiler is higher if hand-firing is used, but with underfeed stokers burning native coal, the watertube boiler is more economical than the cylindrical boiler."

Experience over a period of twenty-eight years has established that mere improved combustion efficiency plays but a minor part in a steam raising plant at sea. The first cost of heat units is not a matter of major importance. These facts are clearly proved, apart from the experience of combustion engineers at sea, by the fact that oil, in which the heat unit may cost fifty per cent more than a heat unit in the form of coal, can make good its claim to have economic advantages over its rival coal. During the discussion of Mr. Muller's and other papers at the meeting of The Institute of Fuel in October, 1930, reference was made to the fact that even today the conditions of purchase of bunker coal were very unsatisfactory. At certain ports, coal was sold by measurement and delivered in cambered bottom barges, the recorded depth for measurement purposes being the maximum and not the average. References were also made to other discrepancies and more or less deliberate spillage. It was also stated that steam plant designers were limited by the necessity of maintaining the good will of ships' engineers by avoiding the use of any equipment which would prolong repairs in port.

If coal is to maintain a place as a fuel for ships' boilers and that coal is for economical reasons to be mechanically fired, then it is necessary that an effort be made on a comprehensive scale, and it must be with the cooperation of the whole shipping organization from naval architects, colliery owners, merchants and agents, the directorate of the shipping lines, to the superintendents and engineers.

The recent attempts to fire ships' boilers with powdered fuel are technically interesting. These efforts may be described as merely a repetition of the work started nearly thirty years ago with mechanical stokers. It has been possible to establish an increased efficiency as was the case with mechanical stokers; experiments have been made with various forms of burners to effect minor improvements just as stoker manufacturers strove to improve details, but as has been shown in the foregoing, such details merely touch the fringe of the problem, and equipment for powdered fuel firing cannot in itself, unsupported by a large contributory cooperation, be more successful than the earlier efforts associated with mechanical stokers. The record of Mr. Muller's achievement in cooperation with Underfeed Stoker Co. Ltd., points the way to success in introducing modern coal burning methods to the marine world.

Mexico's Most Modern Power Station



Torreon Station of the Compañia de Nacional de Electricidad, S. A.

By

F. L. GILMORE

Compania Nacional de Electricidad, S. A.

The author describes the Torreon Station owned by the Compañia Nacional de Electricidad, S.A. and located at Torreon, Mexico. This plant is tied in with the Boquilla hydro-electric station of the Cia. Agricola y de Fuerza Electrica del Rio Conchos, S.A. The initial plans provided for an initial capacity of 12,000 kw. but a deficiency of rainfall necessitated the immediate addition of a 15,000 kw. generating unit. To meet the emergency, a construction program was put through which made power available just nine months from the original conception of the project.

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THE new Torreon (Franke) S. E. Station is located outside of the City of Torreon in order to be as near to the center of load as practicable and to avoid high tension transmission lines in the urban district.

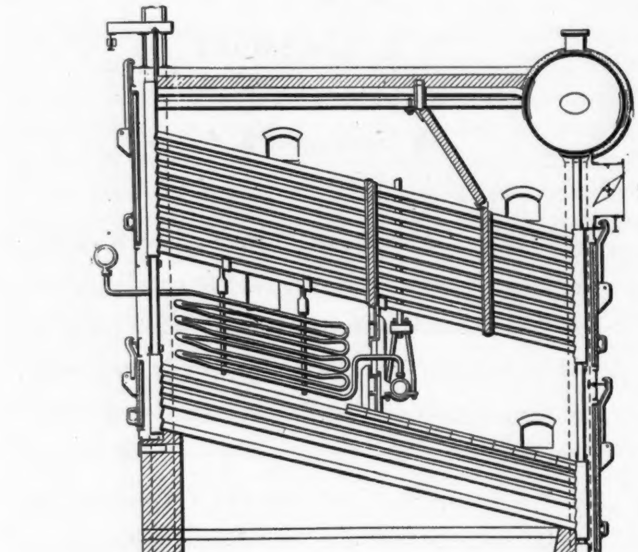
There being no available open water for condensing purposes and as all coal would have to be brought in by rail, more than ordinary latitude was obtained, the only restrictions being proximity to the several branches of the Mexican National Railroad and to insure that the proposed sites would permit the successful drilling of water wells.

The original plan, calling for two 6,000 kw. turbogenerators, was to obtain a firm power supply for the rapidly developing load at Torreon and in the Laguna district with the Boquilla hydro-electric plant of the Cia. Agricola y de Fuerza Electrica del Rio Conchos, S. A. made available as reserve by means of a 132 kv. transmission inter-connection. However, owing to an accumulated deficiency of rainfall the necessity was immediately recognized for early help for the Agricola system from the new station. Therefore, a 15,000 kw. unit was added bringing the total capacity of the new plant up to 27,000 kw. In order to have power available for the Agricola system, it was necessary to establish an exceptionally rapid construction program. Only nine months elapsed from the conception of the project to the time when power was available from the new plant.

The power house structure consists of a relatively light steel frame, with corrugated asbestos roofing and siding. This type of building was chosen, in part because of its relatively low cost, and in part to make possible the rapid construction program above outlined. The design was so laid out that there was a minimum of support or other attachment of apparatus to the structural steel framework, in order not only that the building cost might be kept down, but that the machinery layout might be carried on almost independently of the structural design and that the installation of equipment might proceed before complete erection of the building. Attention was given to the outlines and proportions of the power house, and the architectural appearance is quite satisfactory, considering the conditions.

The turbo-generators installed at Torreon are of General Electric manufacture.

Units 1 and 2 are 6,000 kw. (0.8 power factor), 13,800 v., 3 ph., 60 cyc., 3,600 r.p.m. for throttle steam conditions of 355 lb. gage, 700 deg. fahr., 2 in. Hg. abs. back pressure. They are bled at the first, seventh and tenth stages. Unit 3 is 15,000 kw. (0.8 power factor), 13,800 v., 3 ph., 60 cyc., 1,800 r.p.m., for the same throttle steam conditions as Units 1 and 2. It is bled at the first, sixth and tenth stages. The turbine lubricating oil is continuously reconditioned by one No. 302 De Laval centrifuge. A Bowser two-compartment precipitation tank of 265 cu. ft. capacity is also provided.



Sectional elevation of one of the six duplicate, stoker-fired boiler units installed at Torreon.

All generator cooling air for Units 1 and 2 is filtered through Reed viscous fluid contact type filters, whereas the heat balance for Unit 3 made desirable a condensate cooled air cooler operating in a closed ventilating system.

The two 6,000 kw. units are served by Westinghouse surface condensers, circulating pumps, condensate pumps, and steam jet air ejectors. The condensers have 7,000 sq. ft. of surface, and are two-pass with non-divided water boxes. The circulating water pumps, one for each condenser, are 14.5 c.f.s., 740 r.p.m., 50 ft. head and are driven by 150 hp. motors. The condensate pumps, two for each condenser, each delivers 66,600 lb. per hr. against 200 ft. at 1,160 r.p.m., and are driven by 20 hp. motors.

The 15,000 kw. turbine-generator is served by a Worthington surface condenser, circulating water pumps, pond condensate pump and steam jet air ejectors. The condenser has 16,000 sq. ft. of surface and is a two-pass type with divided two-compartment water boxes. Two circulating water pumps are provided with a capacity of 20.6 c.f.s. each, and are driven by 200 hp. motors. The two condensate pumps each deliver 210,000 lb. per hr. against 30c ft. at 1,100 r.p.m. and are driven by 75 hp. motors.

Six Walsh & Weidner cross-drum boilers made by Combustion Engineering Corporation were installed, each having 8,436 sq. ft. of surface, supplying steam at 400 lb. per sq. in. Each has a normal capacity of 67,500 lb. of steam per hour, but can produce a somewhat higher quantity under forced load.

Each boiler is 16 tubes high by 22 wide, arranged to accommodate an interdeck superheater. The second row of tubes from the bottom was omitted to provide a refrigerating zone; 1,520 sq. ft. Elesco interdeck superheaters are used.

Boiler feed is controlled by Copes thermostatic regulators.

The Mexican coal is expected to have the following average proximate analysis as received:

Moisture..........	1.4 per cent
Ash..............	16.4 per cent
Volatile..........	25.2 per cent
Fixed Carbon......	57.0 per cent
B.t.u.	12,743 per lb
Sulphur...........	1.3 per cent (separately determined)
Ash Fusion Temp.	2500 deg. fahr.

The Combustion Engineering Corporation multiple retort stokers are motor driven. Each has 7 retorts, a width between furnace sidewalls of 12 ft. 4 in., a projected area of 182 sq. ft., and an actual effective grate surface of 191 sq. ft.

The Sturtevant forced draft fans driven by 100 hp. motors have a capacity of 36,200 c.f.m. each, 100 deg. fahr., against a static pressure of 5.75 in. Two additional forced fans have capacity of 36,020 c.f.m. under the conditions given previously.

Two American Blower Company induced draft fans are provided, each having a capacity of 7,060 c.f.m. of gas at 666 deg. fahr.

Worthington Pump & Machinery Corporation supplied three motor-driven boiler feed pumps and a Terry steam-turbine-driven pump, each having a capacity of 0.78 c.f.s. against a total dynamic head of 470 lb. gage at 263 deg. fahr., 3520 r.p.m.

The bleeder heater drip pumps were supplied by Worthington Pump & Machinery Corporation. The evaporator feed, service water and surge tank pumps were supplied by Goulds Pumps, Inc.

Water is obtained from three wells from which it is pumped into a settling basin from and thence into the overhead tanks, the spray pond and other points of use. Due to evaporation, the water in the spray pond becomes more concentrated requiring the treatment of incoming water in order to minimize blowdown. The well water softening plant furnished by the Permutit Company is a zeolite type comprising three 10 ft. dia. by 17 ft. 7½ in. long zeolite pressure tanks.

The pipes and nozzles of the spray pond were furnished by Spraco. There are 160 complete spray groups, each having four No. 11-R nozzles. A wood pipe line connects the condenser discharges to the spray pond.

Coal is dumped from standard 50 ton coal cars into a track hopper which discharges into a skip hoist; from the top of the skip hoist coal may be transferred by means of a chute across the railroad track to a pile on the ground for yard storage by means of a drag scraper. The skip hoist may also discharge on an inclined cross belt conveyor which discharges upon a second horizontal belt conveyor running across the coal bunkers; the latter belt conveyor is equipped with a self-propelled, motor-driven travelling tripper.

The coal handling system has a capacity of 75 tons of coal per hour.

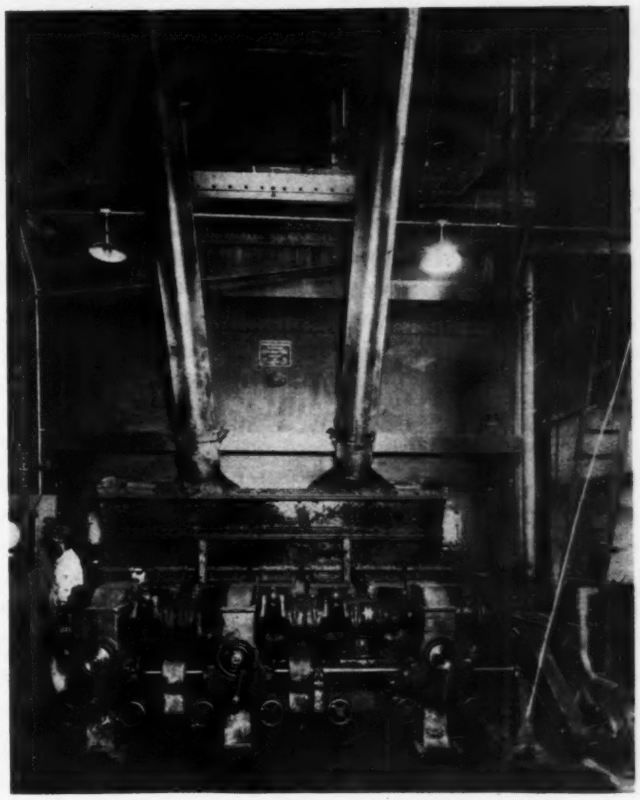
The ashes are taken from the ash hoppers in side dump ash cars which are pushed to a turn table and thence to a ramp where they are pulled up by means of a motor-operated cable for dumping into a hopper; the latter discharges either to a standard railroad car or motor truck.

The following safety features for the coal handling system have been provided:

> A slack cable switch is provided to open the main contactor in case the cable should, for any reason, become slack. The slack cable falls over a cross bar; the weight throws out the switch and cuts off the current.
>
> Hatchway limit switches are located at the top of the skip hoistways, so that if either skip bucket over-travels the upper limit, the current is thrown off and stops the skip hoist motor, thus preventing damage to bucket or skip guide structure.
>
> Safety cutout switches are provided at various points so that the skip hoist cannot be run until the safety switch is closed.

The coal and ash handling system was supplied by Freeman-Riff.

The generator leads are insulated cable on bus supports within the plant and copper tubing from the plant wall to the 13 kv. switch and bus structure which is immediately adjacent and parallel to the plant. This insures the shortest practical distance from generators to their respective switching positions.



One of the six multiple retort stokers installed at Torreon.

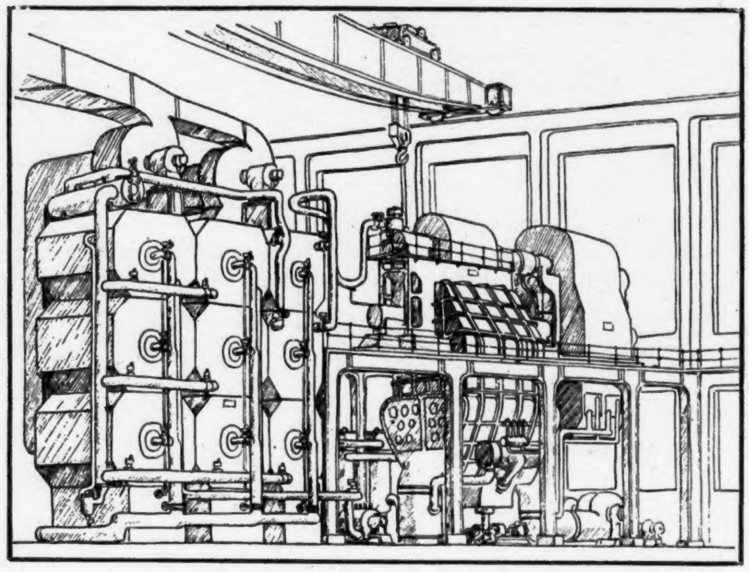
The 13 kv. switch and bus structure consists of a rugged pipe frame with operating bus and inspection or transfer bus, sectionalized between the two smaller units and the larger unit and with oil circuit breakers on both busses for the generators and transformers. The line positions are equipped with oil circuit breakers to the operating bus and gang operated air break switches to the transfer bus. All distribution lines are taken away from the bus structure on specially designed steel towers with individual unit type metering equipments for each circuit. There are a total of six 13 kv. feeders including tie feeder to generating station of the Ferrocarril Electrico de Lerdo a Torreon, S. A. in Torreon proper, a distance of about four miles.

Two 12,000 kva. transformer banks are provided between the 13 kv. bus and high tension switchyard. These are auto transformers 13.8 kv. to 66/132 kv. and physically are placed midway between the 66 and 132 kv. switchyards to simplify connections

(Continued on page 54)

The Boiler Room of the Future*

By GEORGE A. ORROK
Consulting Engineer, New York



THE BOILER ROOM OF THE FUTURE
"A boiler of this (multicellular) type would be self-contained with its auxiliaries, would make no dust or dirt, could be located in the same room as the turbine and generator, and the boiler room, as a boiler room, would disappear."

Mr. Orrok offers conceptions which would indicate that the amazing progress of steam plant practice during the past ten years has not by any means exhausted the immediate possibilities; that we are facing a period in which methods and equipment for the use of fuel and for steam generation will be radically changed. He envisages the passing of solid fuels as such and their use for steam generating purposes in gaseous form only. The boiler room of the future will have no separate entity but will succumb to the merger trend and become a part of the turbine room.

I have many times before this Society set forth the statistics of the production and use of mineral fuel in this country, and have commented on the large rate of increase in the use of such fuels in the last fifty years. In the paper on "Fuel Utilization" which was published in MECHANICAL ENGINEERING in April of last year, I gave the statistics at 10-year periods of the production and use of the various types of fuel, together with a tentative apportionment of the fuels among the various uses of industry. Roughly speaking, we use in this country the equivalent of 25×10^{15} British thermal units per annum, which includes the heat obtained from approximately 600,000,000 tons of solid fuels. Something over half of all our mineral fuel is fired in boilers for the making of steam under most diverse circumstances, running all the way from the small household boiler burning perhaps 8 tons of coal per annum, to the large East River boilers which may use up to 70 tons per hour at their maximum output. One of these boilers running at its average rating will use 40 tons of coal per hour, or approximately 290,000 tons of coal in a 300-day year. The variation in size is thus 1 to 36,000, and is representative of the range and the scope of this paper.

*Presented at the Fourth National Fuels Meeting of the A. S.M.E., Chicago, Ill., Feb. 10 to 13, 1931

Early Developments in Boilers

Before contemplating the future, it is always well to look back over the progress in the art and to consider the changes and improvements made in the generation of steam which have led up to the present-day attainments, and thus draw conclusions as to what may be expected in the future from the lessons of the past. We need not consider the teakettle boiler of Newcomen or the wagon-box boiler of Watt, except to note that these boilers were quite as rudimentary in character as the modern teakettle and consumed only "a few hundred-weight of coals" per day. The chimneys were short, the draft could hardly be measured on a water gage, and the steam pressures carried were of the order of those carried today in the modern cast-iron boiler of the small house-heating system.

The progress from a boiler plant of this type to the Cornish or Lancashire boilers in the England of the next generation or to the return tubular boiler which has been standard in America for small plants for many years, is exceedingly great. English practice followed the internally fired boiler type, and need not concern us here. But the return tubular type used in this country lent itself to excessive duplication,

and the last generation saw many plants which consisted of possibly as many as 50 to 80, or even more, of these boilers, each about 66 in. in diameter and 18 ft. long, set in batteries of 2, 4, or 6, each boiler being provided with a grate possibly 5 ft. square and not more than 16 in. below the shell of the boiler, on which the fuel was burned. These boiler rooms were low and very dark, and the line of boilers usually had piles of ashes in front of the ash doors, while just behind each fireman was a pile of coal from which he fired his boiler. The coal and ash handling was done by wheelbarrows run by the fireman, and the firing of 250 lb. of coal per boiler per hour was a heavy task performed under the worst of conditions. It was conditions like these that led to the invention of the water-tube boiler, which lent itself much better to increasing size, and boilers of two to three times the capacity of the return tubulars soon became common, although the same disagreeable and laborious firing conditions continued for a long time. Within the last year I have been in certain boiler rooms where these same conditions still exist.

Modern Steam Generation

The demand for power in ever-increasing amounts soon forced the manufacturers to the enlargement of the water-tube boilers, which were readily susceptible to improvements in design. The increasing use of fuel led to the invention of mechanical stokers, and later to the firing of coal in powdered form, and boiler sizes and capacities have been increased up to the large units in the East River station which represent the last word up to date in capacity and fuel consumption per boiler. Meanwhile the working conditions for the firemen have improved. Windows have been introduced into the boiler room; mechanical stokers, fed from an overhead bunker with the coal automatically delivered into the stoker through a pipe, have lightened the labor of the fireman. Ash hoppers and ash-disposal machinery have removed the ash pile from the boiler-room floor, and in many cases have eliminated the ash gang. Forced draft and the balanced-draft systems have ventilated and cleansed the atmosphere of the fire room, and from being the darkest, dingiest, dirtiest place in the power station, the boiler room is now open, airy, cool, and reasonably clean. The fireman, or rather the boiler operator, need not dirty his hands, and might easily wear a white shirt while at his work. Even the cost of making steam has been much reduced if the cost of the fuel itself is not taken into account.

But this is not all: the discovery of oil in Pennsylvania brought oil fuel into the boiler room, and we have today many boiler plants fired with oil which follow in general design those built for the use of solid fuel. With the production of oil, natural gas came into use, and good examples of boilers fired with natural gas are perhaps among the finest of present-day examples of the boiler-room art. With these improvements also came the control systems which have been designed to do away with the hand control of fire-room apparatus, and most of our modern plants are more or less automatically controlled with devices of this type.

The Boiler Room of Today

Taken in general, the boiler room of today is a reasonably clean, cool, comfortable building housing the entire steam-generating apparatus, with plenty of light for inspection, with an automatic control so that the boiler operator becomes practically an overseer whose duty it is to see that the various pieces of apparatus function in their normal manner, who only has real work to do in an emergency, and this whether the fuel be coal, oil, or gas. The coal passers and firemen have been superseded by machinery, the ash gang is non-existent, and the boiler-room operatives for a large plant might be cut down to one man as far as real labor is concerned. However, we have not yet been enabled to do away with the "black gang"—the boiler cleaners, who are still with us—because no matter how carefully machinery may be designed and built, at stated times it must be shut down, cleaned, and repaired for the next run. But even this job is not such a serious one where oil or gas is used as the fuel. I have been informed that there are instances of large boilers, oil or gas fired, which have not needed outside cleaning for a whole year at a time, and I know of a number of cases where the internal cleaning of boilers has been reduced to a washing out plus inspection. It is possible today so to treat most of our boiler waters as to give little cause for labor during the inspection period. We have examples of boilers which have run more than 20,000 hours without the loss of a tube, and required only very minor repairs at the end of the period.

Meanwhile boiler efficiency, or rather fuel efficiency, has been increased to a very large extent. In the early boilers not more than 50 per cent of the heat units in the fuel appeared in the steam at the boiler stop valve. Today, with our methods of heat saving and our modern designs, from 88 to 92 per cent is possible in a test; beyond this it has not yet appeared to be reasonable to attempt to go, although we know well that by means of heat exchangers we could probably increase this efficiency to perhaps 96 per cent, but at a cost too high to be considered.

One of the serious drawbacks to the earlier boilers was the fact that every once in a while one of them would burst, spreading destruction around the neighborhood and usually resulting in serious loss of life. The boilers at that time were almost entirely of the shell type, with large diameters and reasonably thin iron plates, and were a constant menace unless great care was exercised in their construction and operation. However, progress in boiler design has cut down the size of shells or—as we now speak of them in the water-tube designs—drums, the thickness of the plates has been increased, steel has been

substituted for iron, and today explosions of well-designed boilers practically never occur. In addition, we have certain designs of boilers for particularly high pressures in which there are no drums and in which the pressure fluid is confined in small tubes of very high strength as compared with the working pressure. Even should one of these tubes fracture, as it sometimes does, the possibility of damage is small indeed and has ceased to be a menace. Our metallurgists are working for the production of better tube and drum materials than those which we have for use at the present time, and there is no doubt that even these small dangers can soon be forgotten.

The foregoing paragraphs may serve to set forth the well-considered, efficient, and economically sound Boiler Room of Today, and we must now consider what the lessons of the past have taught us and what we may expect as a reasonable line of future development toward the Boiler Room of the Future.

Solid Fuels

Our present use of fuel has been set at the equivalent of 25×10^{15} British thermal units per annum. Of this amount approximately 65 per cent represents the use of solid fuels, of which about one-seventh is anthracite coal. One of the serious drawbacks to the use of solid fuel lies in the ash content, and since many of the better deposits of coal in the United States have been exhausted, the ash content of the present supply varies roughly from 8 per cent in the best semi-bituminous coals to around 30 per cent in the fine sizes of anthracite, and much higher in lignites and other classes of coal now little used. The tonnage of ash is large, and its disposal has always been a serious problem. Wherever solid fuel is burned a substantial proportion of the ash is carried through the boiler, up the stack into the air, and scattered over the surrounding country. Roughly, where no dust catchers are used, it is probable that between 2 and 4 per cent of the weight of the coal fired is distributed in the vicinity of the plant as dust, and many experiments have been made to determine the dust fall in industrial communities. The reports of some of the smoke commissions in Great Britain show figures in excess of a thousand tons per square mile per year in certain cases, a most serious handicap to any locality.

Where the coal is burned in powdered form, the amount of dust escaping may be much larger, and even with the best of dust catchers a serious amount of fine dust, not larger than 25 microns in diameter, escapes into the air. Legislation in various countries has been directed against this nuisance, and particularly in England, where the latest law is quite drastic in its application to industrial furnaces. There are, however, methods of burning solid fuel and storing the heat units in gaseous form where none of the dust may escape into the atmosphere. These devices are well known and at the present time are quite satisfactory in operation, although their cost has been such as to prevent their extensive introduction. One of the results of this drastic legislation will be to make this type of apparatus for the burning of solid fuel much more attractive, and the use of complete gasification plants points one way to the solution of the boiler house problem of the future.

Growing Use of Liquid Fuel

The use of liquid fuel has been increasing to a remarkable degree, and at the present time 25 per cent of our yearly fuel supplies represents the use of mineral oil and its products in furnaces and internal-combustion engines. The remaining 8 to 10 per cent represents the use of natural gas, which is now distributed over a large portion of the country through pipe lines to the centers of use. This pipeline network is being rapidly extended, and one firm alone is furnishing large-sized pipe at the rate of over 12,000 miles a year. It is estimated that more than 200,000 miles of pipe line 6 in. and larger in diameter are already in service, and whether our solid fuel will be gasified at the coal mine and transmitted to the point of use through pipe lines, or gasified at places far removed from thickly populated centers and piped shorter distances, is immaterial for this paper. But it would appear that in the near future the dust problem alone will necessitate the use of gaseous fuel for steam raising in the neighborhood of large centers of population. The gas companies well understand this problem, and there is hardly one in the country today which is not considering the making of such arrangements that houses may be heated with gas from their mains instead of with coal-fired furnaces with their attendant ash troubles, dirt in the cellar, and the expense and trouble of handling, storing, and firing the fuel. Installations of this type are being made daily in all of our larger cities at prices which make the householder eager to convert his coal-burning plant into an automatic gas-burning one.

Many of our central stations which have been burning powdered coal as a main source of supply, have their burning arrangements so made that oil may be used as the fuel when it is cheap enough, and many other plants are arranged for the burning of oil or natural gas in the same burner, depending on the cost of the fuel supply. The manifest advantages of fuel in the gaseous form, the ease of control, the cleanliness, the advantages of the mixing burner and combination burners, are already greatly appreciated.

Liquid fuel is a most convenient one for boiler-room purposes. However, it would appear to be much too valuable a raw material to burn in its present form, particularly since there are at present 28,000,000 automobiles in the United States. The future will no doubt see a considerable increase in the number of automobiles and in the use of the distillation products of petroleum. Petroleum resi-

dues will probably always play quite a part in the generation of steam, but the boiler rooms in which they are utilized will not be ideal, and will only be a small proportion of the total number. I do not consider them as representative examples of the boiler rooms of the future.

Boilers of the Future Will Be Gas Fired

After what has been set forth in the last few paragraphs, we may postulate that the boilers of the future will be gas fired. This means that there need be no coal, no storage provisions, no coal-handling appliances. Ash will not be present and therefore dust catchers and the troubles incident to boiler cleaning may be forgotten. The fuel will be brought into the station through a pipe, and the products of combustion, largely carbonic acid and nitrogen, will go out of the chimney in a clean state. The atmosphere will not be polluted with dust, and the coal pile on a windy day will not scatter coal dust over the neighborhood. The house-holder will light his heating boiler in the fall, and, regulating it with a thermostat, he should not have occasion to be aware of its existence till he shuts it off the following spring.

In discussing this paper, one of my friends asked me why, when I had postulated gaseous fuel as the fuel of the future, I did not throw out the boiler plant and generate power with gas engines, thus getting rid of the entire boiler-house problem. I know perfectly well that the gas engine will be used to a certain extent—to how large an extent no one can say—but probably not widely, since its cost has never been brought down to the economical range. There is a field for the gasoline engine, the gas engine, and the Diesel engine, and these fields will be well covered, but the essential cheapness of steam machinery, its flexibility, together with the lack of limitation in size of apparatus, will, in my opinion, keep the steam boiler with us as long as heat engines continue to be our main source of power.

Boilers of the Future to Consist of Unit Cells of the Tube-and-Header Type

Having indicated the solution of the fuel problem, we must turn our attention to the apparatus, which is the boiler, since our subject is the boiler room of the future. We have today discarded the old forms of shell and fire-tube boilers and are coming more and more to a boiler which is a simple collection of tubes connected by headers of the same shape and of but little larger size. The laws of heat transfer are now fairly well known, and the advantages of a very rapid circulation on both the gas and water, sides are thoroughly appreciated. We have at least six designs of boilers with exceedingly good characteristics which contain no large parts and which are truely safety boilers since a serious explosion of any of them is unthinkable. On many of these boilers the only sign that a break has taken place is the falling of steam pressure, which warns the operator that something has happened. The boiler of the future will be built along these lines. There will be no storage of steam in large shells, in fact we shall go back 100 years to the schemes of a Yankee inventor, Jacob Perkins, who believed in and patented the idea that steam should be made when it was wanted, and used immediately, thus making possible the use of any pressure within the thermodynamic range. Such boilers will naturally be very much smaller in size than many of the present-day boilers. With gaseous fuel and the preheating of combustion air, the flame can be made exceedingly short and the heat liberation may be quite large. The combustion space, which today is of considerable size, will be much reduced, and the speed of the products of combustion through the boiler will be very high in order that the heat transfer may also be high. I am inclined to believe that the boiler of the future might be termed a cellular boiler, in that it will be built up of a number of unit cells, each cell using a certain amount of fuel and generating a certain amount of steam, the number of cells in the boiler depending on the demand for steam. A boiler of this type would be self-contained with its auxiliaries, would make no dust or dirt, could be located in the same room as the turbine and generator, and the boiler room, as a boiler room, would disappear.

Conclusions

Summarizing, we may state the following conclusions as to the future.

I—All solid fuel for the making of heat and power in the future will be burned in the gaseous state, necessitating

- *a* Complete gasification plants
- *b* Coking plants where metallurgic applications are desired
- *c* A great development of pipe-line transportation for the distribution of fuel.

II—The development of large-capacity boilers of small physical size, using high speeds and high heat-transfer rates, necessitating

- *a* Excellent burner practice and low excess air
- *b* Absolute safety in boiler construction and design, very small water content, and no large drums
- *c* A high commercial efficiency since installation cost per unit of heat should be much lower.

III—The practical abolition of the smoke and dust nuisance from solid fuel in thickly settled communities.

Humidity of Gaseous Mixtures*

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Humidity plays an important part in combustion calculations. In this second article dealing with the thermal properties of gaseous mixtures, the author explains the significance of the various quantities used in humidity calculations, and discusses the whole subject from a fundamentally correct thermodynamic standpoint. A particular point of interest in this discussion revolves around the value of the apparent latent heat of moisture which condenses from a gaseous mixture, such as products of combustion, in being cooled to atmospheric temperature. There seems to be some uncertainty about this value, as indicated by the different values given by various authorities. The exact value is derived in this article.

IN many industrial processes, the proportion of water vapor contained in the gases involved is of great importance and in some instances it is the controlling influence. Thus, the humidity of atmospheric air supplied for combustion and the amount of moisture contained in the products of combustion must be taken into account in calculating the efficiency of steam boilers. In drying coal previous to or while pulverizing it, the degree of humidity of the hot gases employed determines the amount of moisture removed from the coal.

In the preceding article on the "Thermal Properties of Gaseous Mixtures", it was demonstrated that the usual method of analyzing gases does not indicate the amount of water vapor present. The present article will explain briefly the usual methods of determining the amount of water vapor present in a gaseous mixture as a basis for discussing engineering calculations pertaining to the thermal properties of moist atmospheric air, products of combustion, etc.

Relative Humidity of Atmospheric Air

The proportion of water vapor in atmospheric air is often expressed in terms of "relative humidity." A relative humidity of 70 per cent means that there is present 70 per cent of the maximum quantity of water vapor which can exist at the given temperature in the space occupied by the air. The maximum quantity varies with temperature and can be found by reference to tables of the properties of saturated steam.

At 70 fahr. for example, Keenan's Steam Tables give 869.0 cu. ft. per lb. as the specific volume of saturated steam, so that its density is $1/869.0 = 0.001151$ lb. per cu. ft. at 70 fahr. This is the maximum weight of water vapor a cubic foot of space can hold at 70 fahr. With 70 per cent relative humidity, each cubic foot actually contains $.070 \times 0.001151 = 0.000806$ lb. of water vapor as superheated steam. If the steam were saturated, the pressure exerted by it would be 0.739 inch of mercury equivalent to 0.3628 lb. per sq. in. given in Keenan's Steam Tables for 70 fahr. At 70 per cent relative humidity, the actual vapor pressure is $0.70 \times 0.739 = 0.517$ inch of mercury. The above density and pressure of water vapor for 70 per cent relative humidity at 70 fahr. are independent of the quantities of dry gases present in accordance with Dalton's law.

In many engineering calculations, the ratio of water vapor to dry air is desired. This ratio is readily calculated when the total pressure supported by the moist air and the composition of the dry air are known. The composition of the dry gases in atmospheric air was given in the preceding article entitled "Thermal Properties of Gaseous Mixtures." Under normal atmospheric pressure, 29.921 inches of mercury, the density of dry air is 0.07490 lb. per cu. ft. at 70 fahr. as given in Table II of the preceding article. If the total pressure of moist air having 70 per cent relative humidity at 70 fahr. is 29.921 inches of mercury, the partial pressure of the dry gases therein must be $29.921 - 0.517 = 29.404$ inches of mercury with a corresponding dry air density of $0.07490 \times 29.404 / 29.921 = 0.07361$ lb. per cu. ft. The density of the moist air is thus $0.000806 + 0.07361 = 0.07442$ lb. per cu. ft. and the ratio of moisture to dry air by weight is $0.000806 / 0.07361 = 0.01095$.

It is interesting to note that the density of moist air is less than that of dry air under the same total pressure and at the same temperature because dry gases with an equivalent molecular weight of 28.966 are replaced by water vapor having a molecular weight of 18.0154.

While relative humidity depends upon the quantity of water vapor present in a given space at a given temperature and is independent of the quantity of dry gases present, it is customary to say that a gas is saturated with water vapor and to speak of the relative humidity of atmospheric air. This language may be justified by the fact that as temperature and

pressure change, the dry gases expand or contract with a corresponding variation in the space occupied by the water vapor associated with a given weight of dry gas. Thus, if atmospheric air with 70 per cent relative humidity at 70 fahr. be heated to 80 fahr. under constant pressure, its volume will increase in the ratio (80 + 459.6) / (70 + 459.6) = 1.019. The actual density of the water vapor will therefore decrease from 0.000806 lb. per cu. ft. at 70 fahr. to 0.000806 / 1.019 = 0.000791 lb. per cu. ft. at 80 fahr. The density of saturated steam at 80 fahr. is 0.001578 lb. per cu. ft. corresponding to the specific volume of 633.8 cu. ft. per lb. given in Keenan's Steam Tables. Hence, the relative humidity has decreased from 70 per cent at 70 fahr. to 0.000791 / 0.001578 = 49.5 per cent at 80 fahr. with no change in the ratio of water vapor to dry air.

If cooled under constant pressure, the relative humidity of a gaseous mixture will increase. Thus, if atmospheric air with a relative humidity of 70 per cent at 70 fahr., is cooled to 60 fahr. under normal atmospheric pressure, the density of the moisture becomes 0.000806 (70 + 459.6) / (60 + 459.6) = 0.000822 lb. per cu. ft. As the density of saturated steam at 60 fahr. is 0.000828 lb. per cu. ft., the relative humidity has increased to 0.000822 / 0.000828 = 99.3 per cent.

A slightly lower temperature would produce 100 per cent relative humidity, and any further cooling would result in a partial condensation of the water vapor. The temperature at which 100 per cent relative humidity is reached is therefore called the dew point.

Dew Point Apparatus

The dew point temperature may be found experimentally by cooling moist atmospheric air or any other gas until a film of moisture visibly forms on a polished surface. The polished surface is usually the outside surface of a metal vessel within which ether is rapidly evaporated by bubbling air through it. After the film of moisture has formed, the bubbling is stopped and the vessel allowed to warm up until the film of moisture disappears. The dew point is taken as the average of the two temperatures noted when the film first forms and when it finally disappears.

Suppose the dew point temperature has been found experimentally to be 60 fahr. At this temperature, the pressure of saturated steam is 0.521 inch of mercury and its density is 0.000828 lb. per cu. ft. If the atmospheric pressure is 30 inches of mercury, the partial dry air pressure must be 30.000 — 0.521 = 29.479 inches of mercury. The dry air density from Table II in the preceding article is 0.07634 × 29.479 / 29.921 = 0.07521 lb. per cu. ft. Hence there are present 0.000828 / 0.07521 = 0.01101 lb. water vapor per lb. of dry air.

Since the molecular weight of water vapor is 18.015 and the equivalent molecular weight of dry atmospheric air is 28.966, the ratio of moles of water vapor to moles of dry air is 28.966 / 18.015 = 1.608 times the ratio by weight. Hence, for atmospheric air saturated with water vapor at 60 fahr. under a total pressure of 30 inches of mercury, there is 0.01101 × 1.608 = 0.0177 mole of water vapor per mole of dry gas. More simply, the ratio by moles is equal to the partial pressure of the water vapor divided by the partial pressure of the dry gas, or 0.521 / 29.479 = 0.0177. The ratio by moles is the same for all compositions of dry gas having a given dew point under a certain total pressure—the above weight ratio applies to atmospheric air only.

Wet and Dry Bulb Thermometers

The amount of water vapor present in atmospheric air is more often determined by means of wet and dry bulb thermometers than by measurement of its dew point temperature. The wet bulb thermometer is so called because a cloth wick saturated with water surrounds its bulb. As air flows past this wet bulb, some of the water evaporates. Under the assumption that the latent heat absorbed in evaporating the water is equal to the sensible heat given up by a portion of the air in cooling from the dry bulb to the wet bulb temperature at which this portion becomes saturated with water vapor, we obtain the fundamental equation first derived by Carrier in 1911, namely:

$$r'(w' - w) = (c_{pa} + c_{ps} w)(t - t')$$

where t = initial temperature of atmospheric air as indicated by the dry bulb thermometer,

t' = final temperature of the moisture saturated portion as indicated by the wet bulb thermometer,

w = initial weight of water vapor per unit weight of dry gas in atmospheric air,

w' = final weight of water vapor per unit weight of dry gas in the moisture saturated portion at the wet bulb temperature,

c_{pa} = mean specific heat under constant pressure of dry air between the dry and wet bulb temperatures,

c_{ps} = mean specific heat under constant pressure of superheated steam between the dry and wet bulb temperatures and

r' = latent heat of evaporation per unit weight of water vapor at the wet bulb temperature.

Solving the above equation for the ratio of water vapor to dry air, we obtain

$$w = \frac{r' w' - c_{pa}(t - t')}{r' + c_{ps}(t - t')}$$

The value of w' may be determined from

$$w' = \frac{p_a}{p - p'_s} \quad \frac{d'_s}{d'_a}$$

where p = total pressure of moisture saturated air at wet bulb temperature,

p'_s = saturated steam pressure at wet bulb temperature,

p_a = normal atmospheric pressure,

d'_s = saturated steam density at wet bulb temperature,

d'_a = dry air density at wet bulb temperature and under normal atmospheric pressure p_a.

The above formulas may be conveniently applied to gases other than atmospheric air by basing the various quantities on one mole of gas rather than unit weight. The formulas then become

$$m = \frac{r' m' - c_{pg}(t - t')}{r' + c_{ps}(t - t')}$$

and

$$m' = \frac{p'_s}{p - p'_s}$$

where p = total pressure of moisture saturated air at wet bulb temperature t',

p'_s = saturated steam pressure at wet bulb temperature t',

m' = moles of saturated steam per mole of dry gas at wet bulb temperature t',

r' = latent heat of evaporation per mole of saturated steam at wet bulb temperature t' (18.015 times latent heat per unit weight),

c_{ps} = specific heat per mole of superheated steam between dry bulb temperature t and wet bulb temperature t',

c_{pg} = specific heat per mole of dry gas between dry bulb temperature t and wet bulb temperature t' and

m = moles of water vapor per mole of dry gas at dry bulb temperature.

The value given by the above formulas for the depression of the wet bulb temperature below that of the dry bulb, is a limiting value which is approached with high velocities of the air or other gas flowing past the wet bulb and with high wet bulb temperatures. At low wet bulb temperatures and particularly with low air velocities, there are appreciable errors in the calculated wet bulb depression as shown by the curves of Fig. 1, due mainly to absorption of heat by radiation from surrounding objects being large relative to heat transfer by convection from the flowing air to the wet bulb of the thermometer. The amount of radiant energy absorbed depends upon the emissivity coefficients of surrounding objects and is more or less indeterminate. Also, at low air velocities, the correction necessary to the wet bulb temperature varies considerably with small changes in velocity which are difficult to measure. It is therefore desirable to confine humidity measurements with wet and dry bulb thermometers to high air or gas velocities where the error is so small that it may in most engineering work be neglected.

General Humidity Relations

From the foregoing discussion, it is apparent that whether the humidity of a gas be determined by measurement of the dew point temperature or by readings of wet and dry bulb thermometers, the quantity which can be readily calculated from the experimental readings is the ratio of water vapor to dry gas in the mixture. While this ratio can be conveniently used in most engineering calculations, there are cases where the relative humidity is desired and the density of the moist gas is also often wanted. To serve as a basis for these and other

TABLE I. DRY AND MOISTURE SATURATED AIR UNDER NORMAL ATMOSPHERIC PRESSURE, 29.921 INCHES OF MERCURY

Temperature	Absolute pressure of saturated steam	Density of saturated steam	Density of dry air under normal atmospheric pressure	Density of dry air in moisture saturated air	Density of moisture saturated air	Moisture per lb. of dry air in saturated air	Moisture per mole of dry gas in saturated gas
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
fahr.	inches of mercury	lb. per cu. ft.	lb. per cu. ft.	lb. per cu. ft.	lb. per cu. ft.	lb.	mole
0	0.038	0.000068	0.08630	0.08619	0.08626	0.00079	0.00127
20	0.103	0.000177	0.08270	0.08242	0.08260	0.00215	0.00346
32	0.181	0.000303	0.08069	0.08020	0.08050	0.00378	0.00608
40	0.248	0.000409	0.07939	0.07873	0.07914	0.00519	0.00835
60	0.521	0.000828	0.07635	0.07502	0.07585	0.01104	0.01775
80	1.032	0.001578	0.07351	0.07097	0.07255	0.02139	0.03440
100	1.932	0.002851	0.07088	0.06630	0.06915	0.04300	0.06914
120	3.445	0.004912	0.06844	0.06056	0.06547	0.08111	0.13042
140	5.878	0.008116	0.06615	0.05315	0.06127	0.1527	0.2455
160	9.649	0.01292	0.06402	0.04337	0.05629	0.2979	0.4790
180	15.290	0.01989	0.06202	0.03033	0.05022	0.6558	1.0545
200	23.465	0.02970	0.06013	0.01297	0.04267	2.2899	3.6822

humidity calculations, the following mathematical relations are appended:

$$w = \frac{p}{p - y\,p_s}\,\frac{d_s}{d_a}$$

$$= \frac{1}{1.608}\,\frac{y\,p_s}{p - y\,p_s}$$

$$= \frac{y\,w_s}{1 + 1.608\,w_s(1 - y)}$$

$$m = 1.608\,w$$

$$= \frac{y\,p_s}{p - y\,p_s}$$

$$= \frac{y\,m_s}{1 + m_s(1 - y)}$$

$$y = \frac{1.608\,w}{1 + 1.608\,w}\,\frac{p}{p_s}$$

$$= \frac{1 + 1.608\,w_s}{1 + 1.608\,w}\,\frac{w}{w_s}$$

$$= \frac{m}{1 + m}\,\frac{p}{p_s}$$

$$= \frac{1 + m_s}{1 + m}\,\frac{m}{m_s}$$

$$d_m = \frac{p - y\,p_s}{p}\,d_a + y\,d_s$$

$$= \frac{1 + w}{1 + 1.608\,w}\,d_a$$

$$= (1 - y)\,d_a + y\,d_{sm}$$

$$p_s = \frac{m}{1 + m}\,\frac{p}{y}$$

$$= \frac{m_s}{1 + m_s}\,p$$

where p = total pressure of moist air,

t = temperature of moist air,

y = actual relative humidity of moist air at temperature t,

w = actual ratio by weight of water vapor to

dry air in moist air at temperature t and under total pressure p,

m = actual ratio of moles of water vapor to moles of dry air in moist air at temperature t and under total pressure p,

d_m = actual density of moist air at temperature t and under total pressure p,

p_s = saturated steam pressure corresponding to temperature t,

d_s = saturated steam density corresponding to temperature t,

d_a = dry air density at temperature t and under total pressure p,

d_{sm} = density of moisture saturated air at temperature t and under total pressure p,

w_s = ratio by weight of water vapor to dry air in moisture saturated air at temperature t and under total pressure p,

m_s = ratio of moles of water vapor to moles of dry air in moisture saturated air at temperature t and under total pressure p,

1.608 = 28.966 / 18.015, ratio of molecular weights of dry air and water vapor.

The above relations are applicable to any other gas than air by substituting for 1.608 the ratio of the equivalent molecular weight of the dry gas in question to the molecular weight of water vapor.

Table I contains data for a few temperatures only to illustrate how to prepare a more complete table which may be used with the above humidity relations for atmospheric air under the normal atmospheric pressure of 29.921 inches of mercury. The pressure and density of saturated steam in Columns (2) and (3) were taken from Keenan's Steam Tables for temperatures above 32 fahr. For temperatures below 32 fahr., the pressure of saturated steam over ice was obtained from the International Critical Tables and the density was calculated from the pressure and temperature by the relation

$$d_s = \frac{18.015}{359.0} \times \frac{p_s}{29.921} \times \frac{491.6}{t + 459.6}$$

$$= 0.8245 \frac{p_s}{t + 459.6}$$

where p_s = pressure of steam in inches of mercury,

t = temperature of steam in degrees fahr. and

d_s = density of steam in lb. per cu. ft.

The density of dry air in Columns (4) and (5) was calculated by means of the relation

$$d_a = \frac{28.966}{359.0} \times \frac{p - p_s}{29.921} \times \frac{491.6}{t + 459.6}$$

$$= 13.2565 \frac{p - p_s}{t + 459.6}$$

where p = total pressure of moist air in inches of mercury,

p_s = partial pressure of steam in moist air in inches of mercury,

t = temperature of moist air in degrees fahr. and

d_a = density of dry air in lb. per cu. ft.

The density of moisture saturated air in Column (6) is the sum of the density of saturated steam in Column (3) and the density of dry air given in Column (5) for a partial pressure less than 29.921 inches by the saturated steam pressure in Column (2). The ratio of moisture to dry air by weight in Column (7) is equal to Column (3) divided by Column (5). The ratio by moles in Column (8) is equal to the partial pressure of saturated steam, Column (2), divided by the partial pressure of the dry air in moisture saturated air, 29.921 minus Column (2). The latter ratio applies to any gas under normal atmospheric pressure.

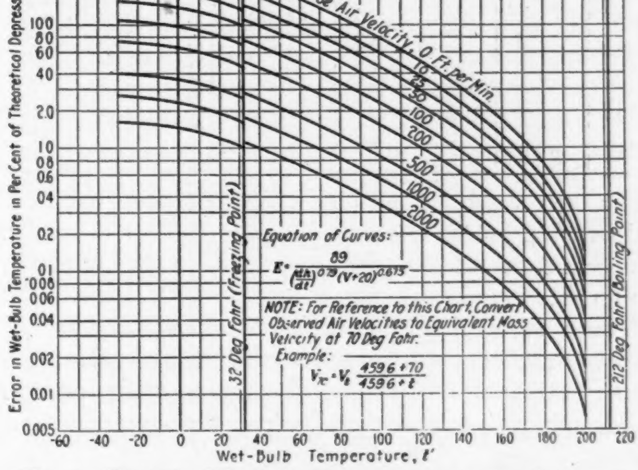

Fig. 1—Error in Wet-Bulb Temperature expressed in per cent of the theoretical wet-bulb depression at wet-bulb temperatures from—30 to 200 deg. fahr. and at transverse air velocities over the wet-bulb ranging from 0 to 2000 ft. per min. Reproduced from paper, "The Temperatures of Evaporation of Water into Air" by Carrier and Lindsay, A.S.M.E. Transactions, 1924.

TABLE II. TOTAL HEAT OF MOISTURE SATURATED AIR UNDER NORMAL ATMOSPHERIC PRESSURE, 29.921 INCHES OF MERCURY

Temperature	Volume of moisture saturated air per lb. of dry air	External work per lb. of dry air	Internal energy per lb. of dry air above 0 fahr.	Internal energy per lb. of ice or water above ice at 0 fahr.	Total internal energy per lb. of saturated steam above ice at 0 fahr.	Total internal energy in saturated steam above ice at 0 fahr. per lb. of dry air	Total heat of moisture saturated air per lb. of dry air
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
fahr.	cu. ft.	B.t.u.	B.t.u.	B.t.u.	B.t.u.	B.t.u.	B.t.u.
0	11.602	31.53	0	0	1167.5	0.92	32.45
20	12.133	32.98	3.43	9.52	1174.2	2.52	38.93
32—	12.469	33.89	5.49	15.38	1178.2	4.45	43.83
32+	12.469	33.89	5.49	158.88	1178.2	4.45	43.83
40	12.702	34.52	6.87	166.93	1180.9	6.13	47.52
60	13.330	36.23	10.30	186.93	1187.8	13.11	59.64
80	14.090	38.30	13.74	206.88	1194.8	25.56	77.60
100	15.083	41.00	17.18	226.81	1201.6	51.67	109.85
120	16.513	44.88	20.62	246.76	1208.2	98.00	163.50
140	18.815	51.14	24.06	266.71	1214.5	185.45	260.65
160	23.057	62.67	27.51	286.72	1220.7	363.65	453.83
180	32.971	89.62	30.96	306.73	1226.7	804.47	925.05
200	77.101	209.56	34.41	326.78	1232.8	2823.0	3067.0

Thermal Changes in Moist Air

So long as the temperature of moist air remains above the dew point, the heat added or abstracted for a given temperature change may be determined for a fixed proportion of water vapor as explained in the article on the "Thermal Properties of Gaseous Mixtures." When the proportion of water vapor varies but the temperature remains above the dew point,

thermal changes may be based on the wet bulb temperature variations as explained later in this article. The thermal changes occurring when the temperature is reduced below the dew point will now be discussed. In this case, partial condensation of moisture results, so that a change in latent heat as well as in sensible heat must be taken into account.

TABLE III. APPARENT LATENT HEAT OF MOISTURE CONDENSED IN COOLING AIR BELOW THE DEW POINT

Dew point temperature	Moisture per lb. of dry air under normal atmospheric pressure	Final temperature	Moisture condensed per lb. of dry air	Heat abstracted per lb. of dry air	Sensible heat to cool moisture and dry air without condensation	Apparent latent heat at final temperature per lb. of dry air	Apparent latent heat at final temperature per lb. of moisture
(1) fahr.	(2) lb.	(3) fahr.	(4) lb.	(5) B.t.u.	(6) B.t.u.	(7) B.t.u.	(8) B.t.u.
120	0.08111	40	0.07592	103.31	22.23	81.08	1068.0
140	0.1527	40	0.1475	188.51	31.09	157.42	1067.3
160	0.2979	40	0.2927	357.45	45.35	312.10	1066.3
180	0.6558	40	0.6506	768.93	76.04	692.89	1065.0
200	2.2899	40	2.2847	2638.1	207.57	2430.5	1063.8
120	0.08111	60	0.07007	90.76	16.67	74.09	1057.4
140	0.1527	60	0.1417	174.52	24.88	149.64	1056.0
160	0.2979	60	0.2869	340.56	37.80	302.76	1055.3
180	0.6558	60	0.6448	744.88	65.19	679.69	1054.1
200	2.2899	60	2.2789	2581.42	181.67	2399.7	1053.0
120	0.08111	80	0.05972	73.55	11.12	62.43	1045.4
140	0.1527	80	0.1313	155.89	18.66	137.23	1045.2
160	0.2979	80	0.2765	319.03	30.25	288.78	1044.4
180	0.6558	80	0.6344	716.21	54.34	661.87	1043.3
200	2.2899	80	2.2685	2520.1	155.75	2364.3	1042.2
120	0.08111	100	0.03811	45.01	5.56	39.45	1035.2
140	0.1527	100	0.1097	125.92	12.44	113.48	1034.5
160	0.2979	100	0.2549	286.19	22.69	263.50	1033.7
180	0.6558	100	0.6128	676.21	43.48	632.73	1032.5
200	2.2899	100	2.2469	2447.5	129.83	2317.7	1031.5

The only accurate method of determining the heat abstracted below the dew point is to base it on the fundamental relation that it is equal to the change in internal energy plus the external work done. The data in Table II were based on this relation and will enable the heat abstracted to be readily calculated for cooling air below the dew point under normal atmospheric pressure between the temperatures listed.

Referring to Table II, the volumes of moisture saturated air per lb. of dry air in Column (2) are the reciprocals of the values in Column (5) of Table I. Column (3) in Table II is obtained by multiplying the volumes in Column (2) by the constant pressure in pounds per square foot equivalent to 29.921 inches of mercury and then dividing by 778.6 ft. lb. per B.t.u. to get $A\ P\ V = 2116.2\ V / 778.6 = 2.718\ V$. By reason of the constant total pressure, the external work for cooling the mixture between any two temperatures is readily calculated per lb. of dry air by subtracting the corresponding values in Column (3). It would be difficult to obtain the external work for either the moisture or the dry air separately due to changes in partial pressures which occur as the moisture partly condenses with decrease in temperature. The internal energies of the constituents are readily calculated, however, for any given initial and final temperatures and corresponding partial pressures.

Thus, the internal energy of one pound of dry air above 0 fahr., given in Column (4), is calculated by the formula below, derived from the one for diatomic gases in the article on "Thermal Changes in Gases," by subtracting 1985 from the first constant to eliminate the external work and then dividing both constants by 28.966 to reduce the internal energy from one mole to unit weight, obtaining:

$$\Delta u = 170.72 \left[\left(\frac{T}{1000}\right) - \left(\frac{T_o}{1000}\right)\right] + 1.38 \left[\left(\frac{T}{1000}\right)^3 - \left(\frac{T_o}{1000}\right)^3\right]$$

where T_o = initial absolute temperature, fahr.,

T = final absolute temperature, fahr.

Δu = change in internal energy, B.t.u. per lb.

The internal energy in one pound of ice above ice at 0 fahr., Column (5), was calculated from the specific heat of ice given in the International Critical Tables. At 32 fahr., the ice melts and its internal energy increases by the latent heat of fusion, 143.5 B.t.u. per lb. The external work done upon the ice in melting under atmospheric pressure is about 0.004 B.t.u. only, so that the internal energy of water at 32 fahr. above ice at 0 fahr. is 158.88 B.t.u. per lb. The internal energy of water above 32 fahr. was obtained by adding this figure to the "total heat of saturated liquid" given in Keenan's Steam Tables, first subtracting the values of A P V at temperatures above which this is equal to 0.01 B.t.u.

To get the total internal energy per lb. of saturated steam above ice at 0 fahr., given in Column (6), the internal energy in steam above water at 32 fahr. was first obtained from Keenan's Steam Tables by subtracting from the tabulated values of total heat the corresponding values of A P V calculated from the tabulated pressures and specific volumes. To these differences was added the internal energy of water at 32 fahr. above ice at 0 fahr., 158.88 B.t.u. per lb. The values so obtained above 32 fahr. were extrapolated graphically to obtain the values tabulated below 32 fahr. Column (7) is the product of Column (6) and the number of pounds of moisture per lb. of dry air given in Column (7) of Table I. Column (8) in Table II. is the sum of Columns (3), (4) and (7), and is the true total heat of moisture saturated air per lb. of dry air in conformity with the definition of total heat given in the article on "Heat and the First Law of Thermodynamics."

TABLE IV. WET BULB TOTAL HEAT OF MOISTURE SATURATED AIR UNDER NORMAL ATMOSPHERIC PRESSURE, 29.921 INCHES OF MERCURY

Temperature	Sensible heat per lb. of dry air above 0 fahr.	Latent heat of evaporation per lb. of saturated steam	Moisture per lb. of dry air	Latent heat of steam per lb. of dry air	Wet bulb total heat of saturated air per lb. of dry air
(1) fahr.	(2) B.t.u.	(3) B.t.u.	(4) lb.	(5) B.t.u.	(6) B.t.u.
0	0	1090.8	0.00079	0.86	0.86
20	4.80	1080.0	0.00215	2.32	7.12
32	7.69	1073.4	0.00378	4.06	11.75
40	9.61	1069.1	0.00519	5.55	15.16
60	14.41	1058.2	0.01104	11.68	26.09
80	19.22	1047.3	0.02139	22.40	41.62
100	24.03	1036.3	0.04300	44.56	68.59
120	28.85	1025.1	0.08111	83.15	112.00
140	33.66	1013.6	0.1527	154.78	188.44
160	38.47	1001.8	0.2979	298.4	336.9
180	43.29	989.8	0.6558	649.1	692.4
200	48.11	977.7	2.2899	2238.8	2286.9

Subtracting the total heats corresponding to two different temperatures does not give directly the heat

abstracted to cool moisture saturated air below the dew point because the different values in Column (8) of Table II correspond to different amounts of moisture per lb. of dry air as given in Column (7) of Table I. In cooling from the dew point to a lower temperature, the difference between the amounts of moisture given in Column (7) of Table I. is the water

TABLE V. MAXIMUM ERRORS IN WET BULB TOTAL HEAT DIFFERENCES

Wet bulb temperature	Moisture per lb. of dry air, w'	Latent heat of evaporation per lb. of steam, r'	Wet bulb total heat per lb. of dry air	Differences in wet bulb total heats	$(r''-r')\,w'$	$0.46\,w'\,(t''-t')$	Total error
(1) fahr.	(2) lb.	(3) B.t.u.	(4) B.t.u.	(5) B.t.u.	(6) B.t.u.	(7) B.t.u.	(8) B.t.u.
0	0.00079	1090.8	0.86				
				6.26	—0.0085	0.0073	—0.001
20	0.00215	1080.0	7.12				
				8.04	—0.0234	0.0198	—0.004
40	0.00519	1069.1	15.16				
				10.93	—0.0566	0.0477	—0.009
60	0.01104	1058.2	26.09				
				15.53	—0.1203	0.1015	—0.019
80	0.02139	1047.3	41.62				
				26.97	—0.235	0.197	—0.038
100	0.04300	1036.3	68.59				
				43.41	—0.481	0.396	—0.085
120	0.08111	1025.1	112.00				
				76.44	—0.932	0.746	—0.186
140	0.1527	1013.6	188.44				
				148.5	—1.801	1.405	—0.40
160	0.2979	1001.8	336.9				
				355.5	—3.57	2.74	—0.83
180	0.6558	980.8	692.4				
				1594.5	—7.93	6.03	—1.90
200	2.2899	977.7	2286.9				

vapor condensed or frozen per lb. of dry air. The total heat tabulated for moisture saturated air at the lower temperature must therefore be increased by the internal energy of the condensed or frozen moisture which is obtained by multiplying the weight of moisture condensed or frozen by the internal energy of water or ice given in Column (5) of Table II. to get the total heat of the mixture at the lower temperature. The volume of the water or ice is so small relative to volume of the saturated air at the lower temperature that it is unnecessary to take into account the external work corresponding to the volume of the water or ice. The heat abstracted in cooling below the dew point is equal to the total heat of moisture saturated air at the dew point as given in Table II. minus the total heat of the mixture at the lower temperature calculated as explained above.

Thus, let us find the heat abstracted in cooling atmospheric air from a dew point temperature of 60 fahr. to a temperature of 20 fahr. Moisture saturated air at 60 fahr. contains 0.01104 lb. of water vapor per lb. of dry air. At 20 fahr., there is only 0.00215 lb. of water vapor per lb. of dry air. Hence 0.01104 — 0.00215 = 0.00889 lb. of water vapor have been changed to ice at 20 fahr., having an internal energy of 9.52 × 0.00889 = 0.08 B.t.u. per lb. of dry air. Total heat of mixture at 20 fahr. = 0.08 + 38.93 = 39.01 B.t.u. per lb. of dry air. Heat abstracted in cooling from 60 to 20 fahr. = 59.64 — 39.01 = 20.63 B.t.u. per lb. of dry air.

Apparent Latent Heat

Instead of determining in the exact manner just described the heat abstracted to cool moisture saturated air or other gas below the dew point, it has become customary to use an approximate method in which the moisture is assumed to remain as vapor until the lowest temperature is reached and then be condensed at this temperature. There evidently exists considerable doubt as to what apparent latent heat should be used at the lowest temperature, as indicated by the inconsistency in the A.S.M.E. Test Codes. In the Test Code for Solid Fuels, a value of 1040 B.t.u. per lb. is given, while in the Test Code for Stationary Steam Boilers a value of 1089 B.t.u. per lb. is given for the condensation of moisture in products of combustion. The correct value of the apparent latent heat may be found by aid of the thermal data in Table II.

This has been done for dew point temperatures of 120 to 200 fahr. and for final temperatures after cooling of 40 to 100 fahr. with the results given in Table III. The sensible heat given in Column (6) was based on the formulas in the article on "Thermal Changes in Gases." A slightly different value of the apparent latent heat would of course be obtained if different specific heats were assumed for cooling the moisture. The apparent latent heat has been plotted in Fig. 2, which shows that its value is lower for higher final temperatures and for higher dew point temperatures. For a final temperature of 70 fahr., the best value to use for the usual percentages of moisture in products of combustion is evidently 1050 B.t.u. per lb. of moisture condensed.

Thermal Changes Based on Wet Bulb Temperatures

Instead of the thermodynamically correct total heat of moisture saturated air given in Column (8) of

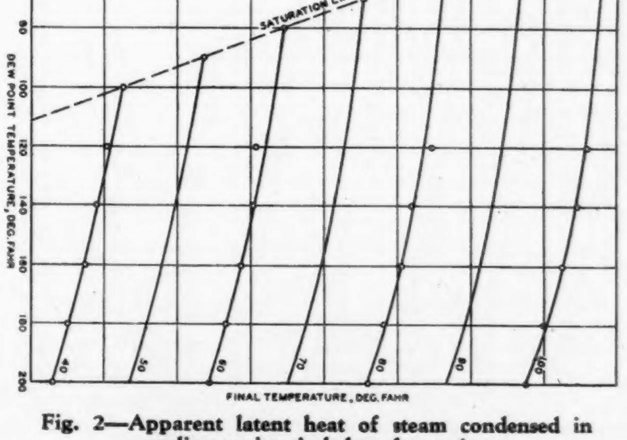

Fig. 2—Apparent latent heat of steam condensed in cooling moist air below dew point.

Table II., a so-called "total heat" has come into use in humidity calculations defined as equal to the sensible heat of one pound of dry air above 0 fahr. plus the latent heat of evaporation of the steam required to saturate the dry air with moisture at the wet bulb temperature. Values of such "wet bulb total heats" are given in Table IV. The sensible

heat per lb. of dry air in Column (2) was calculated by means of the following formula from the article on "Thermal Changes in Gases," the constants being divided by 28.966 to reduce the sensible heat from one mole to one pound of gas:

$$Q = 239.25 \left[\left(\frac{T}{1000}\right) - \left(\frac{T_o}{1000}\right)\right] + 1.38 \left[\left(\frac{T}{1000}\right)^2 - \left(\frac{T_o}{1000}\right)^2\right]$$

The latent heat of evaporation of steam, Column (3), was taken from Keenan's Steam Tables, the values below 32 fahr. being found by graphical extrapolation of the tabulated values above 32 fahr. Column (4) is the same as Column (7) in Table I. Column (5) is the product of Columns (3) and (4). Column (6) equals Column (2) plus Column (5).

Differences between the "wet bulb total heats" in Table IV give approximately the heat added to or abstracted from moist air above the dew point, which heat produces a corresponding change in the wet bulb temperature. Thus, let the temperature of moist air containing w lb. of moisture per lb. of dry air change from t_1 to t_2 by the addition of a certain quantity of heat $(c_{pa} + c_{ps} w)(t_2 - t_1)$ B.t.u. per lb. of dry air. Let the wet bulb temperature before the addition of this heat be t' and afterwards be t''. In accordance with the fundamental equation for the depression of the wet bulb temperature, we have $r'(w' - w) = (c_{pa} + c_{ps} w)(t_1 - t')$ and $r''(w'' - w) = (c_{pa} + c_{ps} w)(t_2 - t'')$. From these equations we obtain by difference

$$\begin{aligned}(c_{pa} + c_{ps} w)(t_2 - t_1) &= [c_{pa}(t'' - t_o) + r'' w''] \\ &- [c_{pa}(t' - t_o) + r' w'] \\ &+ [c_{ps} w (t'' - t') - (r' - r'') w]\end{aligned}$$

The first term in brackets is the sum of the sensible

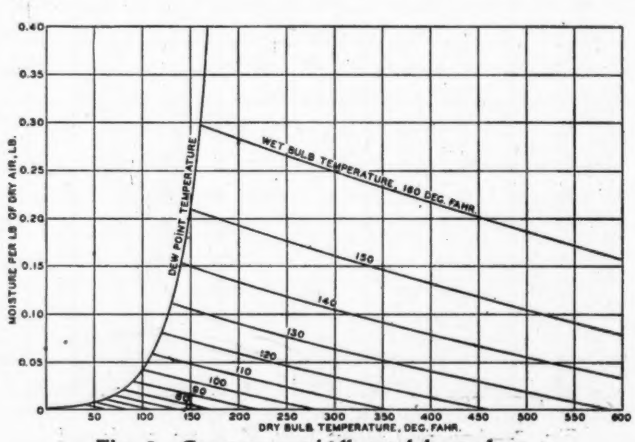

Fig. 3—Constant wet-bulb total heat chart.

heat of one pound of dry air at the final wet bulb temperature t'' above some reference temperature t_o and the latent heat of the steam necessary to saturate the dry air with moisture at the final wet bulb temperature t''. The second term in brackets is the corresponding quantity, or wet bulb total heat, for the initial wet bulb temperature t'. The third term in brackets is the error in assuming the difference between the wet bulb total heats at the initial and final wet bulb temperatures t' and t'' to be equal to the quantity of heat added to the moist air to raise its temperature from t_1 to t_2.

It is evident that the smaller the ratio w of moisture to dry air, the less is the error involved in this

TABLE VI. SPECIFIC HEAT OF MOIST AIR PER LB. OF DRY AIR FOR NORMAL ATMOSPHERIC PRESSURE

Dew point temperature	Moisture per lb. of dry air	Specific heat of dry air per lb. from dew point to		Specific heat of steam per lb. from dew point to		Specific heat of moist air per lb. of dry air from dew point to	
fahr.	lb.	300 fahr.	600 fahr.	300 fahr.	600 fahr.	300 fahr	600 fahr.
fahr.	lb.	B.t.u.	B.t.u.	B.t.u.	B.t.u.	B.t.u.	B.t.u.
0	0.00079	0.2408	0.2418	0.4619	0.4650	0.2412	0.2421
20	0.00215	0.2409	0.2418	0.4621	0.4652	0.2419	0.2428
40	0.00519	0.2409	0.2419	0.4622	0.4653	0.2433	0.2443
60	0.01104	0.2410	0.2419	0.4623	0.4655	0.2461	0.2471
80	0.02139	0.2410	0.2420	0.4624	0.4657	0.2509	0.2520
100	0.04300	0.2411	0.2421	0.4626	0.4659	0.2610	0.2621
120	0.08111	0.2411	0.2421	0.4627	0.4661	0.2786	0.2799
140	0.1527	0.2412	0.2422	0.4629	0.4663	0.3119	0.3134
160	0.2979	0.2412	0.2422	0.4630	0.4665	0.3792	0.3812
180	0.6558	0.2413	0.2423	0.4632	0.4666	0.5450	0.5483
200	2.2899	0.2413	0.2424	0.4634	0.4669	1.3024	1.3115

assumption. The maximum error occurs when the air is initially saturated with water vapor. The maximum errors for 20-degree temperature intervals have been calculated and are given in Table V. These errors are evidently negligible in engineering calculations.

Differences in the wet bulb total heats also measure the heat added to or abstracted from moist air when the moisture content of the air is increased in industrial drying processes. In such processes, the water evaporated may be considered as being first brought to the temperature indicated by the wet bulb thermometer and then vaporized at this temperature by absorption of sensible heat from the moist air. The absorption of moisture by the air does not, therefore, change the wet bulb total heat, which is affected only by the heat required to raise to the wet bulb temperature the water evaporated, to bring to its final temperature the material being dried, to supply heat losses from the drying apparatus, etc. The sum total of these effects is practically equal to the change in wet bulb total heat as demonstrated above.

A chart prepared as indicated by Fig. 3 but to a larger scale, is very convenient for calculations pertaining to drying operations. The curve at the left shows the dew point temperatures corresponding to various ratios of moisture to dry air and was plotted from the values in Columns (1) and (7) of Table I. The inclined lines were plotted for constant wet bulb total heats and therefore represent corresponding humidities and temperatures of moist air which have the same wet bulb temperatures as marked on the curves. Points on these wet bulb temperature curves were obtained by means of the relation

$$H'' = H' + c_m (t - t')$$

where t is the actual temperature of moist air con-

(*Continued on page 46*)

Considerations in the Design of the Small Boiler Plant

PART 2

Mr. Breslove continues his discussion of the various types of equipment entering into the design of the small plant and the factors which determine their selection. In subsequent articles, he will conclude his discussion of equipment and present detailed analyses of design considerations, equipment costs, etc., in connection with a number of existing plants.

By
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Furnaces: The large boiler operating under high ratings will benefit from a specially designed furnace, either with air cooled or water cooled walls. For the smaller boiler, there will be special cases where a similar construction is warranted, but in general, such will not be the case. However, where high ratings are required and a clinkering coal used it is well to use some form of non-clinkering block at the fire line. This may be solid of a special refractory such as carborundum or silicon carbide from which the clinker can be removed by a bar without damage to the brick, or an air cooled block may be installed at the clinker line. Air is fed to the blocks from the wind box. The bridge wall is usually built with air ports supplied with air from the wind box.

Extremely elaborate designs of furnace have been built and remarkable performance obtained from them and in the larger installation they represent the most advanced and approved practice. But for the small boiler they are rarely warranted and the cheaper and more conventional type fills the requirements satisfactorily.

Stacks: Where a new plant is projected, the location of the boiler room and the number of units frequently determines whether the stack should be of brick or steel plate. Where the new boiler or boilers are replacing existing units it will usually be found easier and less costly to furnish each boiler with a separate steel stack; this involves the least amount of engineering and alterations to existing buildings. Sometimes, the location of the plant prohibits the necessary guy wires and a brick or concrete stack with breeching becomes imperative. Where such stack is used, it should be of sufficient height to allow for increased growth of the plant. Frequently, it becomes the governing factor in the ability to replace a small boiler with a larger unit or to change the form of firing so that a greater load can be carried. The resistance through the boiler increases rapidly with increase of load and this should be born in mind. Unlike the steel stack, the height of the brick stack can rarely be increased after it is once built. In some cases, however, the original design of stack and foundation permits an increase in height. Recently, a 7 ft. 6 in. diameter brick stack under the writer's direction came under this class. Its height was increased 20 ft., from 130 ft. to 150 ft. at a cost of $3,400.00. This was accomplished by removing 20 ft. from the original stack, and adding 40 ft. It was rebuilt without interruption to the operation of the plant, and permitted increased rating from the boilers.

A brick stack and breeching will cost more than individual steel stacks but the maintenance is practically zero. The steel stack must be painted frequently and its actual life is limited, but the initial cost is low and it will be found predominant in most of the plants where the boiler units are 500 hp. and under. A brick stack 7 ft. 0 in. inside diameter, 150 ft. high with foundation and breeching for two boilers will cost approximately $10,000.00, whereas two 60 in. dia. steel stacks, mounted on the boilers, will cost about $4,000.00. Where a steel stack is used, it is of the utmost importance that it be supported on a separate steel gallows frame, relieving the boiler brickwork from all strain. This steel gallows may be part of the boiler frame work, but so designed that the weight of the stack is carried through into the foundations and none of it taken directly on the brickwork. Such a scheme is shown in Fig. 1 where the steelwork is part of the boiler structure.

Intimately tied up with the question of stack is that of induced draft. In the modern large station employing economizers or preheaters, the question of induced draft is a very pertinent one and a short steel stack with the breeching outside the boiler room may be very desirable, but for a small unit, it will be only the very exceptional case that would call for an induced draft fan, and this may nearly always be ignored.

In the sections of the country where fuel cost is very high, an economizer must be given serious consideration, but where fuel is comparatively cheap it is not justified and the added cost is not commen-

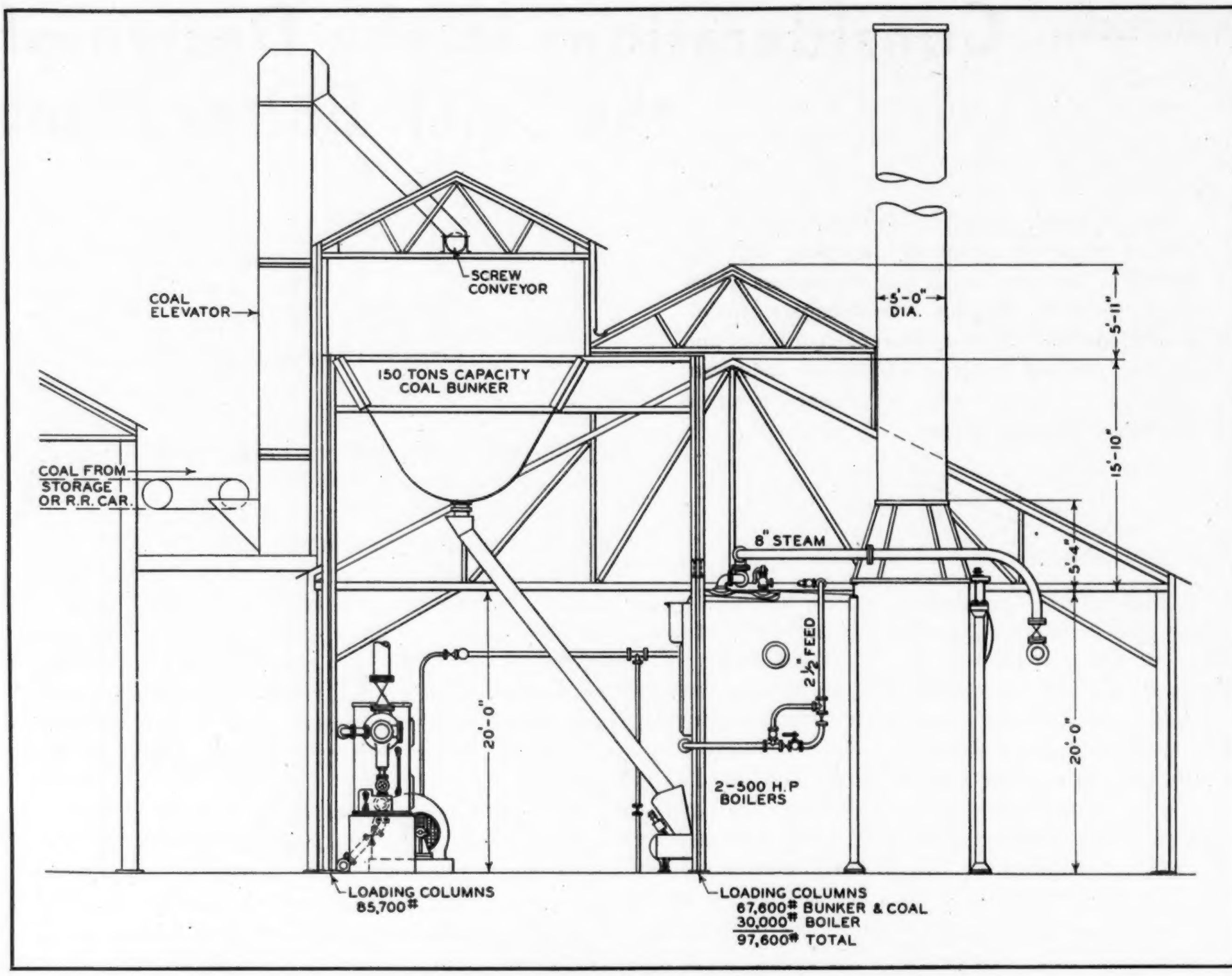

Fig. 1—General arrangement of plant—Pittsburgh Spring & Steel Company.

surable with the savings to be obtained. The question of an air preheater is in a somewhat different class and may be justified in the small plant, as well as in the large one, if the conditions surrounding the installation do not involve too high an initial cost. This applies particularly to the case of pulverized fuel where the preheated air may be mixed with the secondary air supply and result in increased furnace efficiency and reduced power in pulverizing.

Boiler Auxiliaries: The choice of auxiliaries and whether a certain piece of apparatus shall be used or not is a more difficult question to determine than with the larger plant. Certain equipment items have become definitely established in the design of the larger plant but not all of these can pay dividends in the small one.

Superheaters are in order if the plant is a new one and electric generating equipment is to be installed. If, however, the plant is an old one and contains reciprocating engines, a slight degree of superheat may be used to advantage but care must be taken that it is not excessive. The existing piping and auxiliaries as well as the engine may not be adaptable to superheat and considerable difficulty will be experienced in its operation. It is usually the case that the existing plant prohibits the use of superheat because of these factors. Where a new plant is projected, a certain degree of superheat is usually desirable, the degree being dependent on the use to which the steam is to be put and will differ for each installation. In any event, it is well to have the boiler and piping arranged so that a superheater may be added later if found desirable.

Where the boiler feed contains a serious quantity of impurities and solids which will result in priming and foaming it may be desirable to install one of the several so-called "purifiers." Most of these are designed for installation within the boiler drum preventing the solids from coming over into the steam turbine, coating the blades and doing other damage. These devices are particularly valuable where superheat is used since it is essential that clean, dry steam enter the superheater. There are designs which do not require installation within the drum but the former are more in evidence.

Fans: A forced draft fan is the accompaniment of practically every modern stoker installation. The natural draft stoker quickly reaches its limitation. Modern high speed fans have replaced the earlier types of slow speed, engine-driven, straight blade

fans. These fans operate up to speeds of 2,000 r.p.m., or even higher, and may be driven either by a steam turbine or electric motor. Where the exhaust from the turbine can be used, or where only one fan is installed, the steam turbine drive is the more feasible. The single wheel, impulse turbine is a rugged piece of apparatus. It requires but little attention, can be directly connected to the fan through a flexible coupling and speed variation easily obtained through a throttling valve controlled by a pressure regulator or other mechanical device.

The motor-driven unit is desirable where more than one fan is installed or where there is a surplus of exhaust steam. The electric power required for its operation can be manufactured in a large generating unit more economically than in the small turbine. Installation of one motor-driven and one steam-driven fan results in a very flexible arrangement and either may be used as required for the proper heat balance.

Direct current if available, is preferred when using a motor drive. The motor may then be shunt wound and the speed variation obtained through shunt field control, the rheostat being operated from a pressure regulator or similar device. Where only alternating current is available, a wound rotor induction motor is used but its speed variation must not be more than 2:1. Its operation beyond this range becomes unstable and unsatisfactory. Where the initial investment must be kept down to a minimum, the installation of but one fan unit may be considered with safety. It should be turbine driven. Fig. 2 shows one of these units which has been in almost continuous operation for over five years and Fig. 3 a similar unit in service for eight years. Where only one unit is installed, certain spare parts must be held in stock for emergencies. The fan unit may be located on the boiler room floor in front of the boilers where it is accessible and within view of the operator. (See Figs. 3 and 4.) The air ducts are then short and inexpensive and if built of concrete, integral with the boiler room floor the latter forming the ceiling of the ducts, they become a permanent structure requiring no maintenance. There should be a shut-off gate in the duct to each stoker. Either fan may then be used with any boiler. A suitable door in the duct must not be overlooked to permit easy access for cleaning.

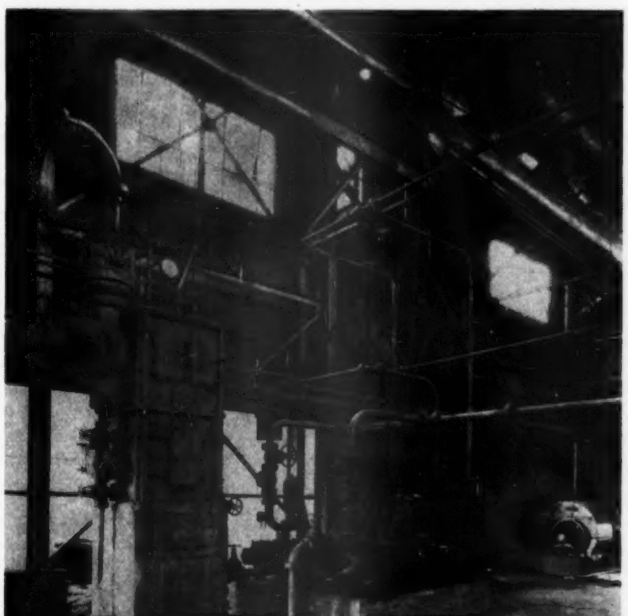

Fig. 2—Partial view of boiler room of Pittsburgh Spring & Steel Company showing forced draft fan and long piping bends.

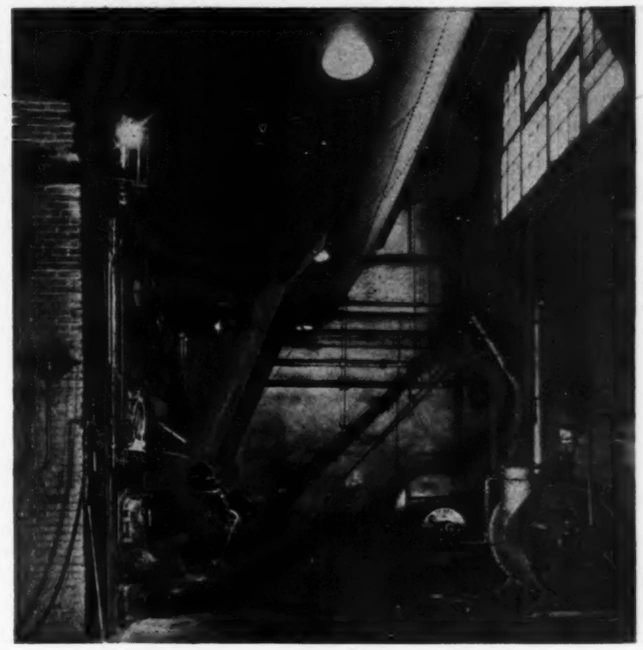

Fig. 3—Boiler room of Hardie Bros. Company showing forced draft fan and steam jet ash conveyor.

Soot Blowers: Almost any boiler of 100 hp. or over should be equipped with mechanical soot blowers. Water tube boilers have been served with mechanical soot blowers for many years and they have been developed particularly for this type of boiler. The return tubular boiler, however, has not been so fortunate; various designs of blowers have come on the market but have been only more or less successful. The problem of the soot blower for a fire tube boiler is more difficult of solution. The writer has installed a number of different types with some degree of success. The most successful consists of a header in the smoke box carrying a series of pipes projecting some distance into the tubes, a reverse turn bend with a steam nozzle being located on the end of each. This is not the only successful type, but it has the advantage of blowing the dust in the direction of the draft and directly into the stack. With forced draft stokers, the fan must be shut off while using the blowers; otherwise, the soot will find its way through the boiler front and out into the boiler room. A soot blower installation on an h.r.t. boiler is shown in the upper left corner of Fig. 5.

Soot blowers for water tube boilers have reached a high state of perfection. The fittings carrying the

blower heads, method of connection to the blower elements and supporting brackets and their attachment to the boiler tubes have been designed with care and their life greatly increased.

The elements in the hot zones receive special metallurgical treatment or are protected by some form of baffle so that their life is prolonged. Some

Fig. 4—Boiler room of Follansbee Bros. Company. Note arrangement of fans.

blowers are built with valve-in-head design and these are preferable. It simplifies the piping, reduces the number of joints, and also saves labor on the part of the operator. But where the conditions do not warrant the added expense of valve-in-head blowers, the ordinary type may be installed and good service obtained from it.

Where but one boiler is installed and the fireman has little to do, it may seem difficult to justify mechanical soot blowers, but they do clean the boiler more thoroughly than the hand lance. Hand cleaning is a dirty, arduous job and it is postponed as long as possible, so that the cleaning is not done as frequently as it should be. It would be difficult, if not almost impossible, to carry high ratings without mechanical soot blowers. This is particularly true with dirty coal. Under such conditions the tubes should be blown about three times per day; otherwise the soot accumulation on the tubes increases the flue-gas temperature and reduces the efficiency of the boiler. The principal object in the installation of mechanical soot blowers is the more thorough cleaning of the tubes. The actual cost of tube cleaning will usually not be less when the cost of steam is taken into account but there are cases where a slight financial saving may be shown. In considering soot blowers, however, the matter should be looked at from the standpoint of the other advantages which accrue therefrom rather than to a direct monetary saving.

Feedwater Heaters and Boiler Feed Pumps: Feedwater heaters and boiler feed pumps cover a wide range; for installation where the maximum load does not exceed 1,000 to 1,500 boiler hp. and the average load is around 500 to 1,000 hp., the direct acting reciprocating pump still has the field. Centrifugal boiler feed pumps are highly desirable where the quantity of water handled is in excess of the range stated or where motor drive is desirable, otherwise the reciprocating pump is the favorite. For pressures of 150 lb. and over the duplex, outside packed plunger pumps give the best service, but for pressures of 100 lb. and under, the piston pump with stuffing box is suitable and the maintenance is low. This type of pump is much lower in price than the outside packed and is just as serviceable under low pressures. It is economy to purchase a boiler feed pump larger than actually required so that the piston speed at the high ratings is not excessive. The wear and tear is thereby greatly reduced, the maintenance is low and the somewhat greater cost for the larger pump is fully justified.

The centrifugal pump is not adaptable to an economical design for small capacities and high heads. The impeller diameter must be comparatively small so that the circumferential opening will be of practical width. Therefore, to obtain the high head required for boiler work it is necessary to have extremely high speeds of rotation or many stages. For example a boiler load of 500 hp. at 200 lb. working pressure means but 30 g.p.m. against a head of

Fig. 5—Boiler room of Crandall, McKenzie & Henderson. Note soot blowers in upper left corner.

almost 500 ft., a very difficult design for a centrifugal pump. On the other hand the plunger pump lends itself admirably to low capacities and high heads.

In either case the pump should be installed so that there is a considerable pressure head over the suction allowing for high temperature of feed without vaporizing. Sometimes it is convenient to set the feed water heater on a gallery and the boiler feed pumps

(*Continued on page 46*)

Interior view of d'Issy-les-Moulineaux Station showing pulverized fuel feeders.

Power Stations in Paris

By DAVID BROWNLIE
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The author describes briefly the six large steam-electric stations serving the city of Paris with particular reference to the recent extension of the d'Issy-les-Moulineaux Station, views of which are shown in the accompanying photographs. . . . These six stations, having a combined capacity of approximately 2,500,000 kw., have been undergoing rapid expansion in the process of which a high degree of modernization has been introduced. The more recently completed extensions to these plants are typical of the most advanced practice in combustion and steam generation.

IT is, of course, impossible to give in any contribution of reasonable length a detailed description of the complicated subject of the supply of electricity to Paris, and of the various power stations involved, especially in view of the great advances that have taken place during the last few years in the production, distribution, and consumption of electricity.

The main object of this article is to present a general description of the power stations serving the electrical needs of Paris, and particularly of the d'Issy-les-Moulineaux plant of the Compagnie Parisienne de Distribution de l'Electricité ("C.P.D.E."). For the accompanying photographs of this station and much of the data presented, the author wishes to acknowledge his indebtedness to the Société Anonyme des Foyers Automatiques of Paris.

The main power stations of Paris, all on the River Seine, as well as a number of smaller stations, which will eventually be closed down, belong to three companies, that is the Union de l'Electricité, the Société de l'Electricité de la Seine, and the Compagnie Parisienne de Distribution de l'Electricité. The latter owns not only the d'Issy-les-Moulineaux Station, but also that of Saint Ouen, while the Société de l'Electricité de la Seine has the Saint Denis and the Ivry Stations, and the Union de l'Electricité controls the Gennevilliers, Vitry-Nord, and Vitry-Sud plants.

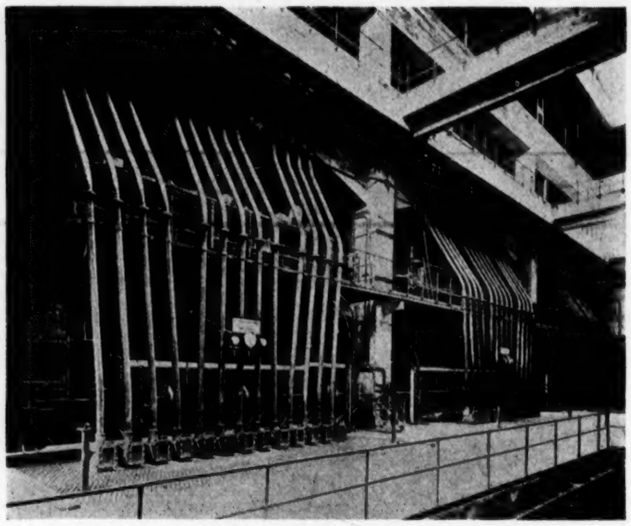
Gennevilliers, of course, commenced in 1920 and extended in 1923, is one of the most important power stations in the world, and has a present capacity of 422,000 kw. The first section of 1920 had a capacity of 240,000 kw., represented by six turbo generators of 40,000 kw. each. The boiler equipment supplying these units comprises five Stirling and ten Babcock and Wilcox boilers, all built in France, operating at 350 lb. pressure and 705 deg. fahr. superheated steam temperature, and equipped with mechancial stokers,

superheaters, and economizers. The Stirling boilers have a normal evaporation of 132,000 lb. per hr. and an overload of 170,000 lb. while the Babcock boilers are 88,000 lb. per hr. normal and 116,000 lb. overload. Some of the units are also equipped with air heaters.

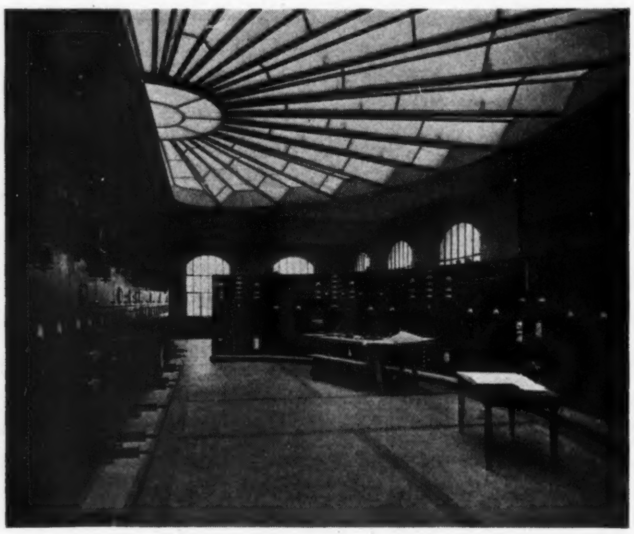
In 1923, there was laid down a further 100,000 kw., comprising two 50,000 kw. turbo generators with four large Ladd-Belleville boilers fired by Lopulco pulverized fuel systems, the normal conditions being 400 lb. per sq. in. pressure and 750 deg. fahr. superheated steam temperature, with 132,000 lb. evaporation per boiler per hour normal, 176,000 lb. overload for six hours, and 242,000 lb. overload for two hours. The equipment included superheaters, economizers, water screens, and water-cooled side walls. This installation attracted great attention at the time, especially as the boilers were the largest in Europe operating on pulverized coal. Some alteration has since been made, the drying equipment originally installed having been superseded by drying in the pulverizing mills. In 1927, a further extension was made including, four new Ladd-Belleville boilers, together with the transformation of one Babcock and Wilcox boiler, from chain grate stokers to pulverized fuel firing.

The Vitry-Nord Station of the Union de l'Electricité was completely revolutionized and much enlarged when taken over from the original Company. The total installation at the present time is 90,000 kw., including four Ladd-Belleville boilers fired with Lopulco pulverized fuel systems and operating at 255 lb. per sq. in. pressure, with a normal evaporation of 132,000 lb. per hr. and 165,000 lb. overload. Equipment includes water screens, economizers and superheaters.

The Vitry-Sud Station is now being erected. This station, situated on the left bank of the Seine, it is believed will be eventually the most important power station in Paris, with an ultimate capacity of 500,000 kw. The first section of 110,000 kw. is nearing completion and will contain six Ladd-Belleville boilers, each with a heating surface of 25,293 sq. ft., and a working pressure of 545 lb. per sq. in. with a superheated steam temperature of 786 to 806 deg. fahr., and feedwater heated to 280 deg. fahr. by means of four-point bleeder heaters from the turbines. The rated evaporation of each boiler is 238,000 lb. per hr., with 298,000 lb. overload. Lopulco pulverized fuel firing on the latest principles is being installed, including water screens and water-cooled surface on both side and rear walls. Pulverized fuel will be supplied to each boiler by two 10-ton per hr., Hardinge mills, with hot air passed through the mills for drying. Each boiler will have five of the new "R" type Lopulco turbulent burners and five Duplex feeders, and will be equipped with superheater, air heater, and economizer. The fuel, representing 80 per cent of small coal with 16 per cent volatile matter and 20 per cent coke breeze, has a heating value of 12,400 B.t.u. per lb. as fired. It is reported that orders have now been placed by the Union de l'Electricité for three more boilers and two additional 55,000 kw. turbines. When these are erected the Vitry-Sud station will have 220,000 kw., or approximately half of its ultimate capacity.



Pulverized fuel feed pipes and burners at d'Issy-les-Moulineaux Station.



Control room at d'Issy-les-Moulineaux Station.

Two other important power stations in Paris are Ivry and Saint Denis of the Société de l'Electricité de la Seine. Not much information can be obtained about the latter, but the total installation is 150,000 kw., and it is reported that notable extensions are to be undertaken, including the installation of four boilers each of 220,000 lb. evaporation per hr., for the striking conditions of 1,000 lb. per sq. in. pressure and 850 deg. fahr. superheated steam temperature. It is planned to equip these units with direct fired pulverized fuel systems.

It will be noticed in connection with these stations how rapid is the progress with high superheated steam temperatures. This also applies to Great Britain, France, Belgium, and Germany, the advance

Interior view of one of water-cooled furnaces taken from below water screen.

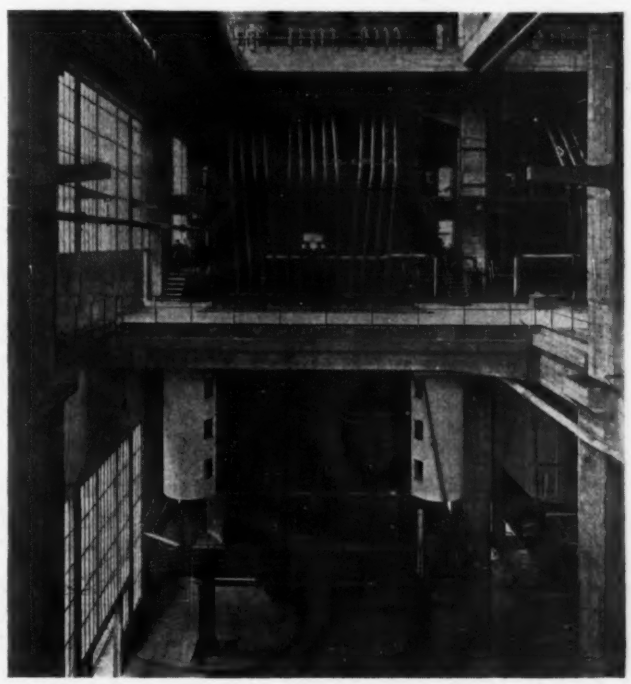
in this particular field being, in fact, more pronounced than in the United States. Thus we have now arrived at the stage when 750 to 900 deg. fahr. is almost standard practice for super-power stations, although it was only a year or two ago that 750 deg. fahr. was regarded as the safe limit for mild steel.

The Ivry Station, placed in operation in the latter part of 1927 and at present having a capacity of 60,000 kw., is also one of the most interesting in Paris. This station, engaged particularly in supplying the Orleans Railway, is also being extended, and according to reports the eventual size will be 200,000 kw. The boiler plant contains six Babcock boilers fired with chain grate stokers. Two new boilers have now been installed equipped for pulverized fuel firing by the Fuller system. The working conditions are 325 lb. per sq. in. pressure and 710 deg. fahr. superheated steam temperature, each of the older boilers having a normal evaporation of 42,000 lb. per hr., and an overload capacity of 60,500 lb., with a heating surface of 6,830 sq. ft. Economizers, superheaters, and air heaters are installed. The two new boilers have a normal evaporation of 60,000 lb. of water per hr., with 80,000 lb. overload. The turbine room contains four 15,000 kw. turbo-generators.

With regard to the stations of the Compagnie Parisienne de Distribution de l'Electricité, the Saint Ouen Station, recently extended by the installation of eight turbo-generators, has a total capacity of 400,000 kw. and is one of the largest power stations in France. The new generators have a capacity of 30,000 kw., each operating at about 230 lb. per sq. in. and 600 to 700 deg. fahr. superheated steam temperature at the stop valve. With the addition of these units, there are in all sixteen turbo-generators in this station, the other and earlier units being smaller in size. The new extension has involved the installation of thirteen Stirling boilers each of 130,000 to 176,000 lb. per hr. evaporation, and three Ladd-Belleville boilers, also with 132,000 to 176,000 lb. evaporation per hr., all equipped with superheaters and economizers and operated at 285 lb. per sq. in. pressure. These boilers are fired by Riley multiple retort stokers of 645 sq. ft. grate area each.

The original equipment at Issy-les-Moulineaux was four 12,000 to 15,000 kw. and two 30,000 to 35,000 kw. turbo-generators, with ten Babcock boilers and thirty Delaunay-Belleville boilers, stoker fired and all of small size, running at 200 lb. per sq. in. pressure and 600 deg. fahr. superheated steam temperature. Recently, however, this station has been extended by the addition of five pulverized fuel fired boilers, each of 220,000 lb. evaporation per hr. normal, with a steam pressure of 625 lb. per sq. in. and a superheated steam temperature of 850 deg. fahr. Three of these units are equipped with Lopulco Burners and the other two with Simon Carves Burners. The new boiler units serve three 35,000 to 40,000 kw. turbo-generators, and some of the existing small turbo-generators are being operated by the exhaust from the new units, rendered possible of course by the much higher steam pressure of 625 lb. per sq. in. as compared with the first section of the plant at only 200 lb. per sq. in. For this reason, the new boilers have been specially designed to allow of extremely flexible working, and although the normal capacity is 220,000 lb. per hr., it is possible to operate at as low as 50,000 lb. and as high as 265,000 lb. with highest efficiency at about 160,000 to 170,000 lb.

The new boilers are all of the forged drum type, the furnaces being of completely water-cooled construction except that two of the units have no horizontal water screens, while the air heaters on all five boilers are of the Usco multiple plate type. The heating surface of each boiler is 19,400 sq. ft. and the furnace heating surface, 2,150 sq. ft. Preheated



Complete exterior view of one of boiler units.

air is supplied by five Usco multiple plate air heaters. All five boilers are operated from a central control station with all the necessary instruments and switches mounted on panels.

It is interesting to note that according to French experience, the best method of using high-pressure turbo-generator sets in conjunction with existing low-pressure sets is to have one high-pressure unit operating direct in conjunction with one low-pressure unit, that is not exhausting from the former into a common low pressure main supplying all the low pressure sets. The practice of installing special boilers of say 1,500 to 1,800 lb. pressure, with the high-speed, high-pressure turbo generator sets exhausting into the existing mains, at any desired pressure, say 250 to 450 lb. does not seem to have come into use in France.

The Compagnie Parisienne de Distribution de l'Electricité has a total capacity of 570,000 kw. in the two stations of Saint Ouen and d'Issy-les-Moulineaux, while the three Companies in Paris altogether control 2,350,000 kw.

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Humidity of Gaseous Mixtures

(*Continued from page 38*)

taining w lb. of moisture per lb. of dry air and having the wet bulb total heat H''. Also, t' is the dew point temperature of this moist air at which the wet bulb total heat is H'. The specific heat c_m of the moist air per lb. of dry air therein may be obtained from Table VI. for normal atmospheric pressure. The mean specific heats from the dew point temperatures to 300 fahr. and to 600 fahr. are given as calculated from the formulas for sensible heat in the article on "Thermal Changes in Gases."

The curves of Fig. 3 show, for example, that moist air containing 0.06 lb. of water vapor per lb. of dry air and having an actual temperature of 480 fahr., has a dew point temperature of about 110 fahr. and a wet bulb temperature of about 140 fahr. Moisture saturated air at 140 fahr. contains about 0.15 lb. water vapor per lb. of dry air. Hence, in a drying process, the hot moist air is capable of absorbing a maximum of 0.15 — 0.06 = 0.09 lb. water vapor per lb. of dry air from water at the wet bulb temperature of 140 fahr.

References

The fundamental equation for wet and dry bulb thermometers by W. H. Carrier was presented in his paper entitled, "Rational Psychrometric Formulae," A.S.M.E. Trans., Vol. 33, pp. 1005-1053, 1911. A later paper by Carrier and Lindsay entitled, "The Temperatures of Evaporation of Water into Air," A.S.M.E. Trans., Vol. 46, pp. 739-780, 1924, discusses the errors in this fundamental equation.

Considerations in the Design of the Small Boiler Plant

(*Continued from page 42*)

directly underneath it as shown in Fig. 6. This results in a short suction line, low friction loss and desirable suction head over the pump.

The most practicable type of feedwater heater for the average plant is the open heater. It is the simplest form of heater and will fit almost all conditions. There will be special cases where hot water is used in process work and it must be absolutely free of oil taint in which case a closed heater may be the only solution. In one plant, the exhaust steam is first passed through a closed heater which supplies hot water for process work and is then taken to the open

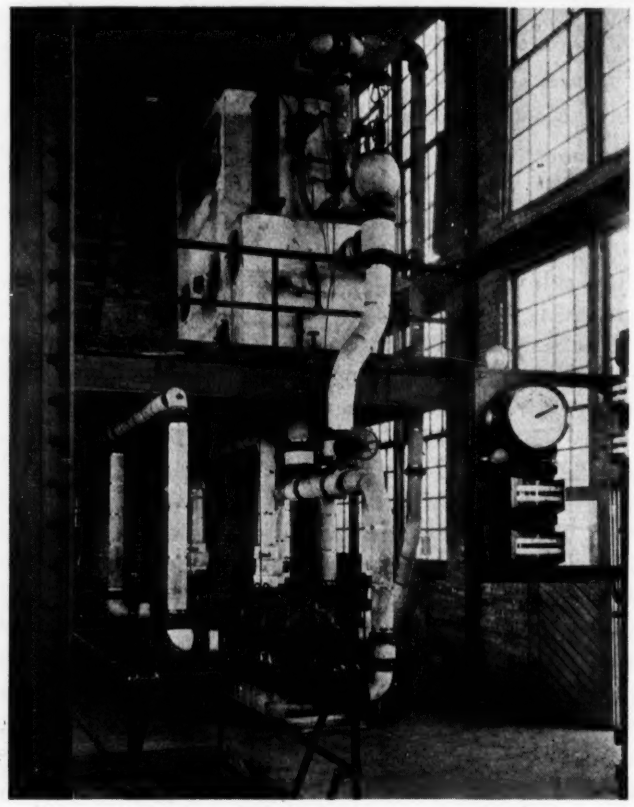

Fig. 6—Arrangement of feedwater heater and boiler feed pumps in plant of Follansbee Steel Company.

heater, the two being in series. As in the case of a boiler feed pump, the open heater should be bought large enough and with plenty of storage capacity so as to give the insoluble impurities such as clay, etc. an opportunity to settle. Where the load is intermittent, the open heater acts as a storage tank and less exhaust steam is wasted to the atmosphere. The latest designs of open feedwater heaters permit the addition of extra storage capacity at but small expense. A small deaerating heater as part of the open heater is very desirable. It expels the oxygen and other gases from the water, preventing corrosion of the boiler surfaces, piping, etc.

These remarks do not apply to plants where steam turbines and stage heating is in effect or to the special cases where the closed heater is indicated.

Economics of Fuel Utilization*

By ALBERT L. BROWN
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This article presents an exceptionally good picture of the entire fuel situation both with respect to industrial and domestic use. The statistics presented are the most recent that have come to our attention. The author offers the conclusion that coal has a heat-value factor that cannot ordinarily be met by other fuels, and that the increased use of other fuels has been due to cleanliness, convenience and other factors which are in line with the higher living standards of the age. Operating to offset these factors are the steps being taken by coal producers to provide a product that will be materially better from the user's standpoint, and the improvement in equipment for burning coal.

BECAUSE of the rapidly changing character of the fuels available and the tremendous improvements in equipment using these fuels the engineers of today are required to weigh and balance facts and conditions with more than ordinary care, in order to select the fuel best suited to their use. They must not only arrive at a decision for the needs of the immediate present, but should be able to justify this choice after a period of several years experience with it. Their forecast into the future, unlike that of the old star-reading astrologer must be based upon material things like fuel reserves, their availability, transportation facilities and costs, plant investment, fuel efficiencies, equipment maintenance costs, and many other important factors.

In some branches of industry a selection is readily made, in others where all fuels must have consideration the choice of one becomes a problem requiring extensive investigation and engineering analysis.

All classes of consumers in the United States during the last few years have established new and high standards of comfort, health, convenience, performance, supply, and value and will continue to set up new ones. The application of these standards extends even to the purchase and use of fuels. Producers and distributors of fuel must meet these requirements in order to market their products successfully.

These conditions have given temporary advantages to one or more fuels and have not only increased the competition between fuels but have been the spur which has resulted in the extensive development of modern equipment for better utilization of all fuels.

*Presented at the Fourth National Fuels Meeting of the A. S. M. E., Chicago, Ill., Feb. 10 to 13, 1931.

At present there is a choice of three primary sources of fuel supply; i.e., coal, petroleum, and natural gas just as in the past, but this year more than ever before some of the immediate effects of one of these fuels when made available to great sections of the country in large volumes through improved methods of distribution will be interesting.

Natural Gas

The present developments in the natural-gas industry will remove in large measure the heretofore restricted territorial use of this fuel, and give to it the qualification of availability which the two other fuels already enjoy. This means that in the future the relative value of this fuel can better be determined because:

1 Of the enlarged distribution area
2 The larger number of industries served
3 Application to be made to a greater variety of types of fuel-burning equipment
4 Of the intensifying of competition between fuels.

Naturally, too, this product in reaching out into new territories will have to assume some of the burdens and difficulties which have been carried by coal and oil. Some of these items are: Increasing cost with increases in distance from the production source; poor load factors; seasonal, industrial, and reduced demand due to the marketing of new fuels; and improvements in utilization equipment favorable to a competing fuel.

Widespread distribution of natural gas will tend to establish quickly the relative importance of each major fuel in a given territory and give the producers and users of each a better guide with which to make future plans and capital expenditures.

From the users' standpoint natural gas can supply energy requirements in a convenient and concentrated form, applicable to his equipment and processes with a minimum labor expense and without the necessity for tying up working capital in a fuel stock pile. Unfailing fuel supply and low cost generally cannot so readily be offered them.

In a country-wide competitive fuel market, therefore, the field of activity for introduction of this fuel will not be in the industries like the electric steam utilities for example where cost will rule it out as against coal. The high-priced domestic heating field is certainly attractive, but here price is not

the major consideration. The character of this load will determine the proportion of this class of business which is desirable and profitable. Inasmuch as house-heating is essentially seasonal and in addition requires special consideration for proper distribution and adequate servicing, progress for natural gas in this field of heating will be relatively slow and largely determined by the gas companies themselves. There is the industrial-fuel demand of general manufacturing business which can afford to pay adequate rates for natural gas. This general class has the load characteristics desired by the gas distributors. This field of consumption will undoubtedly receive more attention in the immediate future from the gas men than any other.

The country-wide distribution of natural gas is new and largely untried. New problems will be presented in reaching into new markets. Some will be overcome while others will be solved more satisfactorily by other fuels.

Petroleum

Petroleum furnished 14 per cent of the total energy supply of the U. S. in 1920. By 1929 this had grown to 25 per cent of a very much larger total figure. The past year in the oil industry has shown no unusual event to prevent this figure remaining at or above this level.

Increased oil and gas production go hand in hand inasmuch as they are found together in most producing areas. The Bureau of Mines states that between 60 and 70 per cent of the natural gas actually utilized is produced in conjunction with the output of crude petroleum. The marketing of new volumes of natural gas will therefore increase the production of oil. The result will be inevitably to increase the competition between these two in the fuel markets.

Unlike the situation a few years ago when it was thought the supply of oil available was the matter of a few years in the future, today we have seen discovered what amounts to practically an unlimited reserve. This has been brought about by the location of new fields and improved scientific prospecting, drilling, and recovery methods.

This increase in fuel supply has been accompanied by an increased production demand for refined products of petroleum particularly in the several transportation industries, and this use has kept a tremendous quantity of oil out of the competitive fuel markets.

Petroleum now stands out as the second largest producer of energy in the country. It ranks next to coal and during the last decade has replaced coal to a considerable extent. This has been true in the field of domestic heating where anthracite particularly has been displaced.

Deliveries of oils in 1929 as reported to the Bureau of Mines totaled 408,735,493 barrels an increase of 2.8 per cent over 1928. However, due to a decrease in export oil the increase for the year within the United States was 4.63 per cent.

This increase in domestic demand for the most part is attributed to the larger requirements of the railroads, bunkers for steamships, of fuel for oil industries, and in the generation of electric power. General manufacturing business also showed an increase for the period.

Oil, like natural gas is increasing in use. It is able to fight its own battles for markets and win a sufficient number of these to be a very disturbing competitor of the other fuels.

Coal

Coal, bituminous and anthracite combined, holds first place among the fuels for furnishing the energy requirements of the United States. In 1929 bituminous coal developed 53 per cent anthracite 8 per cent or 61 per cent of the total from all major sources. This was accomplished by the consumption of over 591 million net tons of coal an amount which would be equivalent to filling 11,800,000 fifty-ton railroad cars, moving them at the rate of 300 one-hundred-car trains each day throughout the year.

To produce enough coal to allow for this consumption 654,494 mining men were employed by 6057 mines of commercial size for 221 days. Each man produced in the average 4.21 tons each working day. The average value of his product at the mines was $2.20. The greater part of it, however, the bituminous coal, sold for only $1.78.

Statistics show that coal has lost tonnage to oil and gas, but as was stated in the beginning, a gain of one fuel over another is an advantage which can only be maintained temporarily and is the result of some new development pertaining to the production or use of the favored fuel which is sooner or later offset by improved utilization of other fuels.

From the foregoing summation it is not hard to note the dependence of the largest part of the population on coal as a fuel. It can also be conceded that coal reserves are so distributed and total to such an imposing figure that coal forced to compete with itself as well as with other fuels should be able to continue as the basic fuel of the United States. The coal mining men of vision know this. They are studying their markets, analyzing the need for coals of certain standards, and estimating the probable demands for each coal. They have realized that the natural product which they produce varies too widely in physical character and chemical quality and they are therefore meeting new standards with mechanized mines, improved preparation underground, mechanical coal cleaners, last-word screening and sizing, and dust-laying equipment. A greater variety of better coals is now offered the consumer than ever before. There is coal today suitable and economical for every kind of consuming unit.

With these new weapons, the coal producer is equipped to hold his present markets and obtain his

fair share of new fuel demands. In this revitalizing of an old and basic industry, the coal men themselves are being actively assisted by the equipment manufacturers who have developed, and successfully applied new coal-burning stokers, pulverizers, and furnaces to the end that coal can supply any need for power more economically and efficiently than any other fuel.

The success which pulverized coal and its application is receiving from industry all over the country has improved the economic position of coal with respect to oil and gas. The rapid elimination of hand-fired coal-burning equipment by modern stoker and pulverizer units is predicted and can be justified from most any angle. The movement of coal from mines to destination points on the railroads of this country employs a large percentage of railroad equipment and personnel, and supplies over 30 per cent of the revenue freight of the railroads. Coal, therefore, is a vital necessity to railroads and their prosperity in turn is essential for the welfare of the whole United States.

It is not surprising to read then that conferences have already been arranged between the sponsors and owners of natural-gas pipe lines and the railroad interests at the suggestion of the latter to consider the interstate character of the pipe lines, as potential competitors of the railroads, and to urge the regulation of the pipe lines by a Federal body like the Interstate Commerce Commission.

The capture of any considerable volume of existing coal markets by natural gas will affect directly not only coal operators, miners and mining communities, but railroads, their employees, and stockholders. A burden to the railroads, from loss of coal revenue can only be compensated for in higher freight rates on all classes of other commodities or losses to railroad employees and stockholders.

The average spot price of bituminous coal at the mines for 1929 was lower than for any year since 1915. A steady dropping off in price has been going on since 1926. The competition for markets and the improvements in methods at mines have improved coal quality and made available increased tonnage. Coal today is a better fuel for less money and when utilized on modern equipment can accomplish more useful work than ever before.

Statistical Review

CONSUMPTION OF FUELS

Year	Bituminous Coal-Net Tons	Anthracite Coal Net Tons	Oil Bbls. 42 Gal.	Natural Gas M cu. ft.
1930	....	....	....	....
1929	519,555,000	71,457,120	369,584,661	1,917,693,000
1928	498,828,000	73,650,080	353,231,875	1,571,880,000
1927	499,801,000	74,671,520	334,271,939	1,455,444,000
1926	532,581,000	77,220,640	334,029,872	....

Division of bituminous coal tonnage by uses was reported in 1928 by Messrs. Tryon and Rogers of the Bureau of Mines as completely as available data would permit as follows:

Distribution of Bituminous Coal by Uses, 1928

	Per Cent
Railroad fuel	27.7
Coke ovens	16.0
Electric utilities	7.7
Steel works	5.4
General manufacturing	
Stone, clay, and glass	4.6
Metal industries (not incl. steel works)	3.5
Food products	2.3
Chemicals and fertilizers	2.1
Paper pulp and printing	2.0
Textiles and products	1.7
Petroleum refining	0.8
Leather and rubber	0.8
Lumber and wood products	0.7
Miscellaneous manufacturing	0.5
Ice manufacture	0.5
Coal and water gas	1.0
Coal mine fuel	1.1
Other mines and quarries	0.8
Bunkers	1.5
Domestic and all others	19.3
Total	100.0

A similar survey of the distribution of fuel oil was reported by E. B. Swanson of the Bureau of Mines in 1930 covering the year 1929. Percentages by industries calculated from this report are shown.

Distribution of Fuel Oil by Uses, 1929

	Per Cent
Railroads	20.52
Steamships (incl. tankers)	24.92
Gas and electric power plants	8.52
Smelters and mines	1.91
Iron and steel products	5.51
Chemicals and allied industries	1.13
Automotive industries	.87
Textiles and their products	1.28
Paper and wood pulp	.81
Logging and lumbering	.61
Cement and lime plants	.90
Ceramic industries	.64
Food industries	1.87
Other manufacturing	3.68
Commercial heating	4.78
Domestic heating	1.94
U. S. Navy army transport, etc.	1.73
Used as fuel by oil companies	15.20
Miscellaneous uses	3.18
	100.00

Average price paid by railroads in 1929 = 86.7c per bbl.

The oil consumption for domestic heating also shows the rapid growth of oil largely at the expense of coal for this use.

Year	Barrels
1929	17,640,000
1928	14,271,000
1927	11,709,000
1926	9,080,000

Distribution of Natural Gas by Uses 1929

	Per Cent
Domestic purposes	19.00
Fuel for oil and gas field and natural gasoline operations	36.45
Manufacture carbon black	13.77
Public utility electric generation	5.67
Petroleum refineries	5.67
General industrial purposes	19.44
	100.00

Natural Gas in Texas, 1929

The state of Texas is the largest producer of natural gas in the United States followed by Oklahoma and California. The most recently available figures are

	M.c.f.	Per Cent
Sold to domestic consumers	25,662,563	14.4
Sold to industrial consumers	120,793,362	67.7
Sold to others (mostly in oil and gas fields)	32,005,415	17.9
	178,421,340	100.0

(Continued on page 54)

The Combustion Characteristics of Natural Gas

By B. J. CROSS

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THE combustible constituents of natural gas except for a few gases that contain small quantities of hydrogen sulphide, consist entirely of methane (CH_4) and ethane (C_2H_6). The equation for the combustion reactions of these gases are·

$CH_4\ (16) + 2O_2\ (64) = CO_2\ (44) + 2H_2O\ (36)$

$C_2H_6\ (30) + 3\frac{1}{2}O_2\ (112) = 2CO_2\ (88) + 3H_2O\ (54)$

Thus one volume of methane requires two volumes of oxygen or (2 x 4.76), 9.53 volumes of air for its combustion. The heat generated in the combustion of 1 cu. ft. of methane at 60 deg. fahr. is 1,009 B.t.u. By dividing 1,009 by 9.53 we find that one volume of air will generate on combustion with methane 106 B.t.u.

One volume of ethane requires 3½ volumes of oxygen or 16.67 volumes of air for its combustion. As the heat value of ethane at 60 deg. fahr. is 1,764 B.t.u., it may be seen that one volume of air will generate on combustion with ethane 106 B.t.u.

Thus the volume of air in cubic feet at 60 deg. fahr. required for combustion of a natural gas is equal to its heating value expressed in B.t.u. per cubic foot at 60 deg. fahr. divided by 106. This relation holds only for conditions of atmospheric pressure and 60 deg. fahr. temperature, the basis on which volumetric gas analyses are commonly reported.

The figures in parenthesis in the two equations given are the relative weights of the substances in the reaction. They are the molecular weights multiplied by the number of molecules. In the combustion of methane, 16 parts by weight of methane combine with 64 parts of oxygen to form 44 parts of carbon dioxide and 36 parts of water. One part, for example 1 lb. of methane therefore requires 4 lb. of oxygen or (4 × 4.31), 17.24 lb. of air for its combustion.

Since the heat value of 1 lb. of methane is 23,838 B.t.u., 1 lb. of air will generate on combustion with methane, 1,382 B.t.u. Similarly, 1 lb. of ethane requires 3.733 lb. of oxygen or 16.09 lb. of air for its combustion. The heat value of ethane is 22,226 B.t.u. per pound and 1 lb. of air generates on combustion with ethane, 1,382 B.t.u. Thus, we have another useful relation: *The weight of air required for the combustion of 1 lb. of natural gas is equal to the heat value expressed in B.t.u. per pound divided by 1,382.*

The equations for the combustion characteristics of fuels given in the preceding article of this series apply also to gases. It is necessary, however, to convert the analyses, which are usually given in volumetric form, to a gravimetric basis. This procedure for a representative natural gas is given in Table 1 below. The proportion by weight and the per cent by weight are first determined by multiplying each constituent gas by its molecular weight. The gases are then divided into their elements in proportion to the atomic weight of each element. The total of column c divided by 100 gives the average molecular weight for the gas. As the molecular weight in pounds of any gas occupies 379.5 cu. ft. at 60 deg. fahr. (359 cu. ft. at 32 deg. fahr.), the volume of 1 lb. of gas at 60 deg. fahr. equals 379.5 divided by the molecular weight and the heat value in B.t.u. per pound is the product of this quotient and the heat value in B.t.u. per cubic foot.

The volumetric and gravimetric ultimate analyses of three representative natural gases are given in Table 2. The combustion characteristics have been plotted in the chart on the opposite page. The gases selected represent a high, a medium, and a zero ethane gas. It will be noticed that the curves for the three gases fall close together. The curves for practically all natural gases with the exception of those gases which contain considerable amounts of CO_2 will fall within these groups.

TABLE I — REDUCTION OF VOLUMETRIC ANALYSIS — NATURAL GAS B

	a per cent by volume	b molecular weight	c =(a×b) proportion by weight	d per cent by weight	Ultimate Analysis C	H_2	O_2	N_2	S
Methane-CH_4	83.5	16	1336	73.2	54.9	18.3	—	—	-
Ethane-C_2H_6	12.5	30	375	20.5	16.4	4.1	—	—	-
Carbon dioxide-CO_2	.2	44	9	.5	.2	—	.3	—	-
Nitrogen-N_2	3.8	28	106	5.8	—	—	—	5.8	-
Hydrogen Sulphide-H_2S	0	34	0	0	—	—	—	—	-
Total	100.0	—	1826	100.0	71.5	22.4	.3	5.8	0

Average molecular weight 18.26 — Cubic feet per pound 60 deg. fahr. = 379.5 divided by 18.26 = 20.78 — B.t.u. per cubic foot = 1,061 — B.t.u. per pound = 22,080.

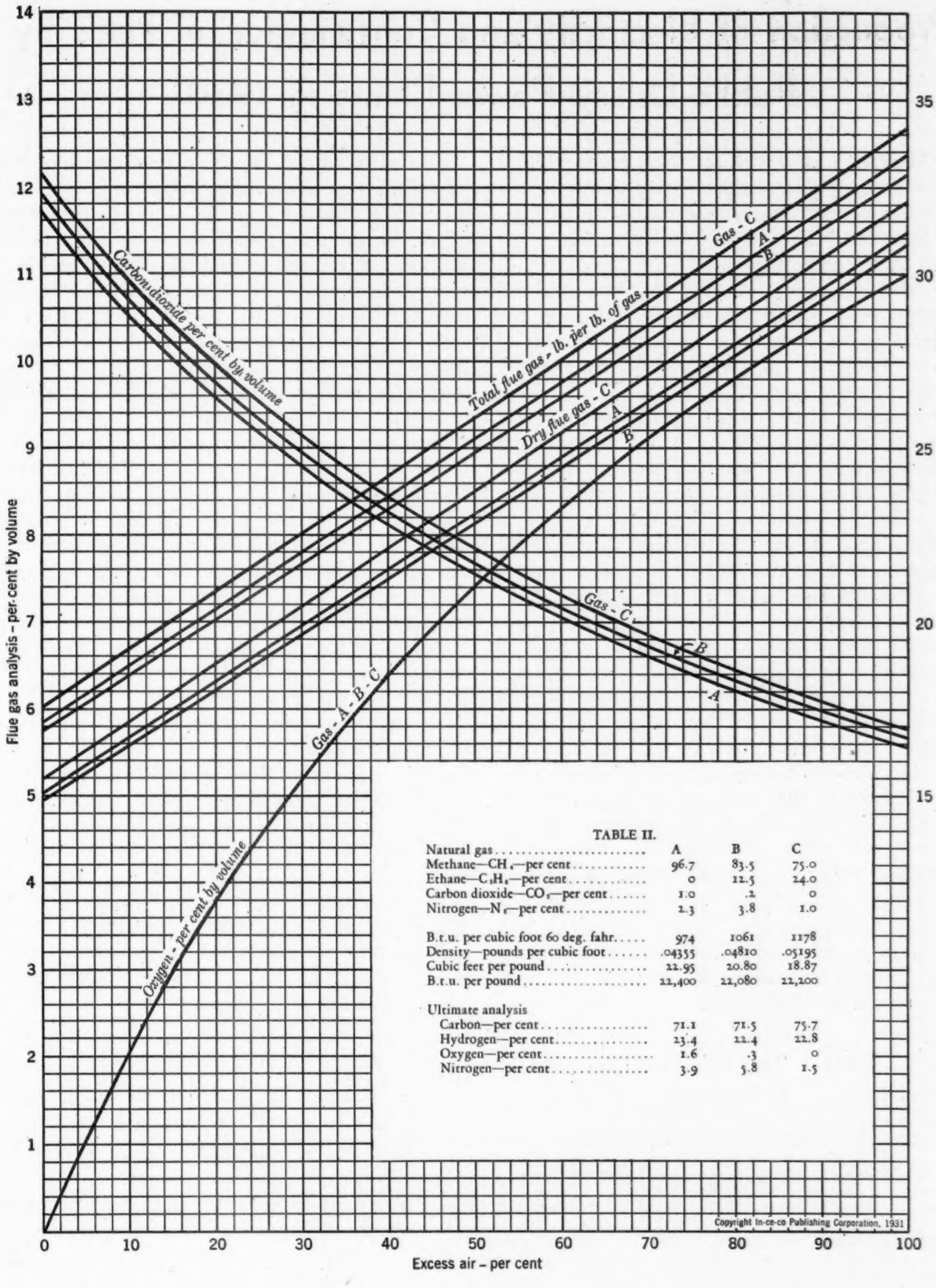

TABLE II.

Natural gas	A	B	C
Methane—CH_4—per cent	96.7	83.5	75.0
Ethane—C_2H_6—per cent	0	12.5	24.0
Carbon dioxide—CO_2—per cent	1.0	.2	0
Nitrogen—N_2—per cent	2.3	3.8	1.0
B.t.u. per cubic foot 60 deg. fahr.	974	1061	1178
Density—pounds per cubic foot	.04355	.04810	.05195
Cubic feet per pound	22.95	20.80	18.87
B.t.u. per pound	22,400	22,080	22,200
Ultimate analysis			
Carbon—per cent	71.1	71.5	75.7
Hydrogen—per cent	23.4	22.4	22.8
Oxygen—per cent	1.6	.3	0
Nitrogen—per cent	3.9	5.8	1.5

CHART SHOWING COMBUSTION CHARACTERISTICS OF THREE REPRESENTATIVE NATURAL GASES

No. 20 of a series of charts for the graphical solution of steam plant problems.

Production of Electricity and Consumption of Fuels by Public-Utility Power Plants in 1930*

PRELIMINARY figures of the total production of electricity by public-utility power plants in the United States in 1930 indicate an output of 95,638,000,000 kilowatt-hours, a decrease of nearly 2 per cent from the output in 1929.

This is the first year since 1921 that the total annual production of electricity was less than in the preceding year, but in making comparisons it should be kept in mind that 1929 was a year of maximum production in most industries.

The production of electricity by the use of water power in 1930 was about 5 per cent less than that in 1929, which in turn was about 0.3 per cent less than that in 1928. These decreases were due mostly to the deficiency in precipitation during 1929 and 1930, which decreased the flow of streams utilized for water power. In 1930 the precipitation in 40 States was less than normal and in 18 States all previous records of low precipitation were broken.

The production of electricity by the use of fuels in 1930 was a little more than in 1929. The consumption of fuel, however, was nearly 4 per cent less. In 1929, 62.3 billion kilowatt-hours of electricity was generated by the consumption of 52.6 million tons of coal. In 1930 the figures were 62.4 billion kilowatt-hours and 50.6 million tons, or 2 million tons less coal than in 1929. The average quantity of coal consumed in generating 1 kilowatt-hour of electricity in 1930 was about 1.62 pounds. This is about half the average for 1919. The decrease year after year in the average consumption of fuel by public-utility power plants is a remarkable achievement, especially in recent years, when the average has been approaching the possible minimum.

The information in the accompanying tables is based on the figures of production of electricity previously published in the monthly power reports issued in mimeographed form by the Geological Survey, Department of the Interior. The output of central stations, both commercial and municipal, electric railway plants, plants operated by steam railroads generating electricity for traction, and Bureau of Reclamation plants and that part of the output of manufacturing plants which is sold are included in these monthly reports. The output of central stations and electric railway plants represents about 98 per cent of the total of plants of all types. The figures published by the National Electric Light Association and the Electrical World include the output of central stations only. Reports are received by the Geological Survey from plants representing over 95 per cent of the total capacity. The output of those plants which do not submit reports is estimated; therefore the figures of output and fuel consumption as reported in the accompanying tables are on a 100 per cent basis.

The accompanying tables show the output and fuel consumption for 1929 and 1930 for the United States and its main divisions and the annual figures of output and fuel consumption and average fuel consumption per kilowatt-hour from 1919 to 1930. The figures for 1930 are preliminary and are subject to revision.

A final report which will give the total output of each State for 1930 will be published in April and will include the final revision of previously published figures due to the receipt of data after the release of the monthly reports.

AVERAGE CONSUMPTION OF COAL PER KILOWATT-HOUR BY PUBLIC-UTILITY POWER PLANTS IN THE UNITED STATES, 1919–1930

Year	Output by the use of fuel (coal, oil, and gas)		Consumption of coal and coal equivalent of oil and gas			
			Total		Per kilowatt-hour	
	Kilowatt-hours	Change from previous year (per cent)	Net tons	Change from previous year (per cent)	Pounds	Per cent of rate in 1919
1919	24,175,000,000	......	38,880,000	......	3.2	100
1920	27,248,000,000	+12.7	41,420,000	+ 6.5	3.0	94
1921	25,863,000,000	— 5.1	35,240,000	—14.9	2.7	84
1922	30,234,000,000	+16.9	38,000,000	+ 7.8	2.5	78
1923	36,088,000,000	+19.4	43,522,000	+14.5	2.4	75
1924	38,808,000,000	+ 7.5	43,130,000	— .9	2.2	69
1925	43,264,000,000	+11.5	44,780,000	+ 3.8	2.1	66
1926	47,274,000,000	+ 9.3	45,856,000	+ 2.4	1.95	61
1927	49,995,000,000	+ 5.8	45,910,000	+ .1	1.84	57
1928	52,793,000,000	+ 5.6	46,387,000	+ 1.0	1.76	55
1929	62,284,000,000	+18.0	52,574,000	+13.3	1.69	53
1930[1]	62,448,000,000	+ 0.3	50,622,000	— 3.7	1.62	51

[1]Figures for 1930 are preliminary and subject to revision.

*From February 12, 1931 report of U. S. Department of the Interior, Geological Survey.

ANNUAL PRODUCTION OF ELECTRICITY BY PUBLIC-UTILITY POWER PLANTS IN THE UNITED STATES, 1919–1930

Year	Total		Water power			Fuel power		
	Kilowatt-hours	Change from previous year (per cent)	Kilowatt-hours	Per cent of total	Change from previous year (per cent)	Kilowatt-hours	Per cent of total	Change from previous year (per cent)
1919	38,921,000,000	......	14,606,000,000	37.5	......	24,315,000,000	62.5	......
1920	43,555,000,000	+11.9	16,150,000,000	37.1	+10.6	27,405,000,000	62.9	+12.7
1921	40,975,000,000	— 5.9	14,970,000,000	36.5	— 7.3	26,005,000,000	63.5	— 5.1
1922	47,654,000,000	+16.3	17,207,000,000	36.1	+14.9	30,447,000,000	63.9	+17.1
1923	55,665,000,000	+16.8	19,343,000,000	34.8	+12.4	36,322,000,000	65.2	+19.3
1924	59,014,000,000	+ 6.0	19,969,000,000	33.8	+ 3.2	39,044,000,000	66.2	+ 7.5
1925	65,870,000,000	+11.6	22,356,000,000	33.9	+11.9	43,514,000,000	66.1	+11.4
1926	73,791,000,000	+12.0	26,189,000,000	35.5	+17.1	47,602,000,000	64.5	+ 9.4
1927	80,205,000,000	+ 8.7	29,875,000,000	37.2	+14.1	50,330,000,000	62.8	+ 5.7
1928	87,851,000,000	+ 9.5	34,747,000,000	39.6	+16.3	53,104,000,000	60.4	+ 5.5
1929	97,352,000,000	+10.8	34,629,000,000	35.6	— 0.3	62,723,000,000	64.4	+18.1
1930	95,638,000,000	— 1.8	32,789,000,000	34.3	— 5.3	62,849,000,000	65.7	+ 0.2

ANNUAL PRODUCTION OF ELECTRICITY BY PUBLIC-UTILITY POWER PLANTS IN THE UNITED STATES 1929 AND 1930

	Output (Thousands of kilowatt-hours)								
	Total			By use of water power			By use of fuel		
	1929	1930	Change per cent	1929	1930	Change per cent	1929	1930	Change per cent
United States	97,352,385	95,637,865	—1.8	34,628,994	32,788,611	— 5.3	62,723,391	62,849,254	+ 0.2
New England	6,608,790	6,392,493	—3.3	2,023,622	2,134,592	+ 5.5	4,585,168	4,257,901	— 7.1
Middle Atlantic	24,784,453	25,125,096	+1.4	6,471,586	6,183,008	— 4.5	18,312,867	18,942,088	+ 3.4
East North Central	23,333,008	22,161,858	—5.0	2,510,972	2,216,830	—11.7	20,822,036	19,945,028	— 4.2
West North Central	5,675,445	5,978,377	+5.3	1,588,418	1,436,151	— 9.6	4,087,027	4,542,226	+11.1
South Atlantic	11,901,577	10,888,071	—8.5	6,562,191	5,104,662	—22.2	5,339,386	5,783,409	+ 8.3
East South Central	3,623,146	3,657,632	+1.0	2,799,899	2,762,696	— 1.3	823,247	894,936	+ 8.7
West South Central	4,896,023	5,001,008	+2.1	73,272	63,541	—13.3	4,822,751	4,937,467	+ 2.4
Mountain	3,966,610	3,704,330	—6.6	3,281,603	3,014,817	— 8.1	685,007	689,513	+ 0.7
Pacific	12,563,333	12,729,000	+1.3	9,317,431	9,872,314	+ 6.0	3,245,902	2,856,686	—12.0

ANNUAL CONSUMPTION OF FUEL IN THE PRODUCTION OF ELECTRICITY BY PUBLIC-UTILITY POWER PLANTS IN THE UNITED STATES, 1919–1930

Year	Coal		Fuel oil		Gas	
	Short tons	Change from previous year (per cent)	Barrels	Change from previous year (per cent)	M cubic feet	Change from previous year (per cent)
1919	35,100,000	......	11,050,000	......	21,406,000	......
1920	37,124,000	+ 5.8	13,123,000	+18.8	24,702,000	+15.4
1921	31,585,000	—14.9	12,045,000	— 8.2	23,722,000	— 4.0
1922	34,179,000	+ 8.2	13,197,000	+ 9.6	27,172,000	+14.5
1923	38,966,000	+14.0	14,684,000	+11.3	31,433,000	+15.7
1924	37,556,000	— 3.6	16,630,000	+13.3	48,443,000	+54.1
1925	40,222,000	+ 7.1	10,246,000	—38.4	46,521,000	— 4.0
1926	41,311,000	+ 2.7	9,399,000	— 8.3	53,207,000	+14.4
1927	41,888,000	+ 1.4	6,782,000	—27.8	62,919,000	+18.3
1928	41,350,000	— 1.3	7,158,000	+ 5.5	77,326,000	+22.9
1929	44,937,000	+ 8.7	10,124,000	+41.4	112,707,000	+45.8
1930	42,897,000	— 4.5	9,036,000	—10.7	120,213,000	+ 6.7

Note: Figures for 1930 are preliminary and subject to revision.

ANNUAL CONSUMPTION OF FUELS BY PUBLIC-UTILITY POWER PLANTS 1929 AND 1930

	Coal (net tons)			Oil (barrels)			Gas (M cubic feet)		
	1929	1930	Change per cent	1929	1930	Change per cent	1929	1930	Change per cent
United States	44,937,230	42,897,256	— 4.5	10,124,216	9,036,087	—10.8	112,706,617	120,212,553	+ 6.7
New England	3,144,180	2,739,868	—12.9	1,668,369	1,769,000	+ 6.0	0	0	0
Middle Atlantic	14,070,427	13,956,310	— 8.0	326,554	321,928	— 1.4	91,306	87,857	— 3.8
East North Central	16,994,350	15,590,716	— 8.3	79,699	105,942	+32.9	4,070,810	4,275,693	+ 5.0
West North Central	4,030,538	4,186,569	+ 3.9	945,909	833,888	—11.8	11,743,112	13,863,072	+18.0
South Atlantic	3,822,774	4,096,871	+ 7.2	2,262,438	2,256,964	— 0.2	153,082	94,348	—38.4
East South Central	867,697	825,711	— 4.8	97,713	109,034	+11.6	3,425,106	4,094,829	+19.6
West South Central	1,228,001	874,328	—28.8	926,078	892,581	— 3.6	65,476,803	70,592,724	+ 7.8
Mountain	681,861	618,076	— 9.4	420,806	481,138	+14.3	832,071	1,030,527	+23.8
Pacific	97,402	8,807	—90.4	3,396,650	2,265,612	—33.3	26,914,327	26,173,503	— 2.8

Mexico's Most Modern Power Station

(*Continued from page 27*)

from the transformers to the respective yards. The 13 kv. leads which of necessity are of considerable length are copper tubing carried on pipe "H" frame structure.

Both the 66 kv. and 132 kv. switchyards are of modern open type with copper tubing busses and connections. The busses in each case are carried on pipe supports and all overhead equipment on individual structural steel towers.

Lightning arresters are provided on the 13 kv. distribution circuits only, with surge protectors on the generator leads at the point where they enter the building.

Station auxiliary transformers consisting of four 800 kva., three phase, 13,800-2,400 volts are tapped solidly to the generator leads between the machine and the 13 kv. structure and are included within the generator differential protection. The remaining transformers consist of three 200 kva., three phase, 2,400-240 volts and one 50 kva. lighting transformer. The principal auxiliary bus operates at 2,300 volts and is of the ring type. All motors of 40 hp. capacity and over are connected to this bus. Switching of these 2,300 volt circuits is by means of oil circuit breakers remotely operated from push button stations located near the motors. The 220 volt motors are controlled by means of enclosed type air circuit breakers.

An extensive grounding network is provided for the complete protection of operators and equipment. Yard illumination is of the most modern design with refractor type units mounted on separate poles.

All oil circuit breakers are remotely controlled from the control room located at turbine floor elevation in the south bay of the plant immediately adjacent to the 13 kv. structure. Auxiliary switchboard is at ground elevation just below the main switchboard.

All high tension breakers are interlocked with their respective air disconnecting switches and with the line grounding switches by key interlocks to prevent faulty operation.

In addition to the 13 kv. distribution feeders there is a 66 kv. line feeding a substation located at Chavez in the center of the Laguna agricultural district.

As expressed at the opening, the Torreon station is tied into the north with hydro stations of the Cia. Agricola y de Fuerza Electrica del Rio Conchos, S.A. by means of a 132 kv. wood "H" frame single circuit transmission line from Torreon to the Boquilla plant of the Agricola system, a distance of approximately 186 miles. At present, hydro electric energy of the Agricola stations is supplemented by power from the Torreon station over this line. Exchange of power may be made in the opposite direction whenever surplus hydro energy exists.

Economics of Fuel Utilization

(*Continued from page 49*)

Forty per cent of the people of Texas are within reach of natural gas distribution for domestic purposes.

The companies reported the average of prices obtained for gas sold in 1929:

	Domestic	Industrial
For distributing companies	39.7c—$1.11	12c—44.9c
Out of these averages the Gas utilities averaged	66.7c	22.3c
Companies exclusively producing	2.6 —7c	
Companies exclusively transmission	16.3—27.6c	

The above figures show the higher economic value of coal as a fuel when competing against oil and natural gas. Assuming the practical burning efficiency of each fuel to be 80 per cent which is possible with each fuel under proper conditions.

Coal has	10,000 B.t.u. per lb.
Coal	15,000 B.t.u. per lb.
Fuel oil	125,000 B.t.u. per gal
Natural gas	1,000 B.t.u. per cu. ft.
Prices: Maximum and Minimum	
Coal	$9.00 and $1.78 per net ton
Oil	12c and 2.06c per gal.
Natural gas	66.7c and 22.3c per M.c.f.
Then:	B.t.u. per 1c
Coal (of 10,000 B.t.u.) at $1.78	89,888
Coal (of 15,000 B.t.u.) at 1.78	134,832
Coal (10,000) at 9.00	17,777
Coal (15,000) at 9.00	26,666
Oil for 2.06c	48,544
Oil for 12.0c	8,334
Natural gas at 22.3c	35,874
Natural gas at 66.7c	12,000

These calculations show that coal has a heat-value factor which cannot ordinarily be met by other fuels. It also proves that such success as oil and gas have made has been largely won from the standpoint of cleanliness, convenience, and other present-day factors of a higher standard of living. It is also possible to read in the figures that cheaper coal is not needed to maintain the present coal output and would not be effective as a means to increase the use of coal generally. The addition of 25c to the selling price of a ton of coal, which would be largely compensated for by increased fuel value under modern methods of preparation, would still leave coal with a safe margin of economic value over the other fuels.

It is therefore urged that all engineers and other fuel consumers weigh carefully the merits of coal when contemplating the selection of a fuel, study its inherent values which up to now have only been partially recovered due to the limitations of utilization equipment, become more familiar with the production and preparation of coal at the mines, and benefit in a material way by the replacement of old and inefficient coal-burning equipment with modern combustion units.

Consumer standards demanded of fuel can be maintained and improved by the use of coal as fuel. Cooperation between the interested groups is needed to bring this about. Engineers will be expected to lead the way.

NEWS

Pertinent Items of Men and Affairs

W. P. Yant Receives Bureau of Mines Appointment

W. P. YANT

W. P. Yant has been appointed supervising engineer of the Pittsburgh Experiment Station United States Bureau of Mines, to succeed G. St. J. Perrott who recently joined the research staff of the A. O. Smith Corporation, Milwaukee, Wis.

Immediately following graduation from the College of Wooster, Wooster, Ohio, in 1918, Mr. Yant joined the staff of the Chemical Warfare Service at American University, Washington, D. C., where he assisted in the development of gas mask absorbents for war gases.

Following the war, Mr. Yant was instructor in chemistry at the College of Wooster. He joined the gas laboratory staff of the United States Bureau of Mines in 1920 and was assigned to problems pertaining to mine, industrial and fuel gases. In 1923 he was appointed chemist-in-charge of the Bureau's gas laboratory and in 1925 he became supervising chemist of the health laboratory section.

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The Bailey Meter Company, Cleveland, Ohio, announces the appointment of P. S. Dickey as Research Engineer. Mr. Dickey is a graduate in Mechanical Engineering of Purdue University and during the past few years has been specializing on Automatic Combustion Control problems for the Bailey Meter Company.

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The New York Edison Company has announced that, on February 17, Floyd L. Carlisle, chairman of the board of the Niagara Hudson Corporation, was elected chairman of the board and Frank W. Smith was elected a vice-president of the Company. Matthew S. Sloan was reelected president.

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The Diamond Power Specialty Corporation, Detroit, manufacturer of soot blowers, water columns and gage glasses, has appointed the Arthur E. Jones Company, 417 S. A. & K. Building, Syracuse, N. Y., as sales representative in the Syracuse district.

New Safety Code for Coal Cleaning Plants

An action unique in the history of the safety movement has just been taken by the American Standards Association, 29 West Thirty-ninth Street, New York with the approval of a national accident prevention code for a process in which not a single serious accident has yet occurred. The new code is aimed at the prevention of dust explosions in pneumatic cleaning plants for coal, according to an announcement made February 11, by the Association. Practically all coal was formerly washed with water. It was found, however, that cleaning could be done more efficiently with air.

Each of the fifty other national safety code projects completed or in process of development under the auspices of the American Standards Association has followed a long series of fatalities or injuries or a spectacular disaster which led the industry concerned to request the establishment of a safety code. In the case of coal pneumatic cleaning plants, the use of which started only a comparatively few years ago, however, there has not been a single serious dust explosion.

The work on the preparation of the code was carried on by a technical committee under the direction of the U. S. Department of Agriculture and the National Fire Protection Association. The code contains comprehensive provisions for the construction and ventilation of buildings in which pneumatic screening and cleaning equipment and driers are located. It also provides for the safeguarding of equipment, and covers various suggested methods of dust collecting.

New Chicago Laboratory to X-Ray Steel

THE Claud S. Gordon Steel X-Ray Laboratory has been organized to make available to industry, metallurgical radiography whereby X-Ray examination of metals up to 4½ in. thickness may be made to determine the presence of inherent defects.

The new laboratory is located at Western Avenue and 15th Place, Chicago, with general city offices at 708 West Madison Street, Chicago, and a branch office at 1988 East 66th Street, Cleveland.

This new laboratory is reported to be the only one of its kind west of New York.

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Illinois Testing Laboratories, Inc., 141 West Austin Avenue, Chicago, has appointed Porter Hurd, 516 Packard Building, Philadelphia, as its representative in Eastern Pennsylvania, Southern New Jersey, Delaware and Maryland for its line of Pyrometers, Resistance Thermometers and other measuring instruments for industrial purposes.

NEW CATALOGS AND BULLETINS

Any of the following publications will be sent to you upon request. Address your request direct to the manufacturer and mention COMBUSTION Magazine

Air Flow Chart

An interesting chart is available for the graphical determination of losses due to friction in the flow of air through pipes and ducts. On the back of the chart, formulas are given and several examples are solved to illustrate the use of the chart. Ask for Chart No. 105. 8½ x 11—Bayley Blower Company, 1938 South Fourth Street, Milwaukee, Wis.

Combustion Control

Two combustion control devices are presented in a new bulletin. The A-JACKS Steam-Damper Regulator provides automatic control of dampers, fuel feed and fan speed for any type of furnace or firing method. The regulator is compensated for gradual movement and has positive adjustment by a hand wheel to maintain the desired boiler pressure. The A-JACKS Over-Fire Control is designed to maintain furnace pressure of individual boilers at the point of maximum combustion efficiency by gradual damper movement to compensate for air flow through the fuel bed. Both devices are fully described and illustrated and application arrangements are shown. 16 pages, 8½ x 11—National Regulator Company, 2301 Knox Avenue, Chicago.

Dust Sampling Apparatus

The Bagtest Dust Sampler was developed in response to a demand for a simple and accurate device for determining the dust loading of gases under varying conditions. The fan is driven by a universal motor which can be attached to the nearest 110 volt lighting circuit. All necessary instruments are included and the results may be quickly compiled by the use of data and tables which are furnished. The sampler will operate under minus pressures up to 15 in. of water and will handle gas volumes of 40 to 65 cu. ft. per minute. A new pamphlet gives the details. 4 pages, 8½ x 11—Dust Recovery Company, 15 Park Row, New York, N. Y.

Feed Water Regulator

The Campbell Feed Water Regulator is presented in a new bulletin which describes and illustrates the unique principle on which this regulator operates. The rate at which feed water is admitted to each boiler is automatically governed by the rate of steam output from the boiler. The regulator is simple and easy to install. Details of design and application arrangements are followed by specifications and price lists covering a wide range of types and sizes. 16 pages and cover, 8½ x 11—Atlas Valve Company, 282 South Street, Newark, N. J.

Interior Painting

A new folder explains the Vortex method of painting interior walls and ceilings of power plants and industrial buildings. Vorcolite is an inside paint made especially for mechanical application by means of spray apparatus which is loaned to the user by the paint manufacturer. The advantages given for this method of application include: saving in labor cost; saving in time; minimum interference with plant operation and a superior surface. 6 pages, 3½ x 6¼—The Vortex Manufacturing Company, 1978 West 77th Street, Cleveland, O.

Refractory Arches and Walls

Detrick refractory arches and walls are presented in a new catalog. This publication is arranged as a handbook for refractory furnace engineers and is printed with attractive color treatment. Several sections are devoted to explaining the underlying principles of Detrick air-cooled walls and arches with photographic illustrations of the structural elements used. Other sections exhibit numbers of representative installations. Useful tables and charts are included for calculating the heat transfer through refractories, figuring the air required for cooling, and giving general information that the designer constantly requires. 80 pages, 8½ x 11—M. H. Detrick Company, 140 South Dearborn St., Chicago.

Refractory Cements

A new booklet describes R & E Refractory Cements and their use. The opening chapter covers the fundamental purposes of refractory cements. Next, various R & E cements are presented and their use for hot patching, cold patching and monolithic furnace linings, is discussed. An interesting section of the bulletin gives information for pre-casting refractory blocks and furnace shapes. Stic-tite, a mineral fibre insulating cement, is also described. 16 pages and cover, 5 x 7—Refractory and Engineering Corporation, 50 Church Street, New York, N. Y.

Steam Specialties

New Catalog No. 12 presents the entire Durabla line of steam specialties including packing, gaskets, gage glasses, valve discs and pump valves. In addition to descriptions and specifications of Durabla products, this booklet contains engineering data pertaining to packing, gaskets, etc. Dimension tables and price lists are included. 80 pages and cover, 4½ x 8¾—Durabla Manufacturing Company, 114 Liberty Street, New York, N. Y.

Small Stoker Unit

A new folder describes the C-E Stoker Unit, a self-contained underfeed stoker with electrical drive and integral fan construction. This stoker provides a simple and reliable automatic machine for firing small boilers, up to 150 hp. This stoker has a number of features not available in other machines of this size, such as, agitated grate bars, side dumping grates and agitated feed hopper which eliminates arching of the coal and interrupted feed. The design is self-contained, completely enclosed and provides a simple, rugged and dependable unit for the underfeeding of coal under small boilers. Three sizes are available with coal burning capacities of 300 lb., 600 lb. and 1000 lb. of coal per hour respectively. 4 pages, 8½ x 11—Combustion Engineering Corporation, 200 Madison Avenue, New York, N. Y.

Variable Speed Transmission

A handbook of Variable Speed Control, recently issued, was compiled for ready reference and includes: Specific requirements for speed control, by industries and for particular machines in those industries; engineering data pertaining to variable speed control; description of new designs of Reeves Variable Speed Transmissions; complete service manual covering the installation and maintenance of the Reeves transmission and additional information relating to variable speed drives. The data is comprehensive and is well presented and the book is bound in a handsome red cloth cover. 72 pages, 4 x 6¼—Reeves Pulley Company, Columbus, Ind.

Vertical Steam Engines

Troy-Engberg Vertical Steam Engines are described in new Bulletin No. 304. These engines are enclosed, self-oiling with piston valve. The single cylinder type is built in sizes from 1 hp. to 100 hp. and the twin engines are built in sizes from 1 hp. to 200 hp. They are fitted with throttle governor for either constant or variable speed service, and automatic flywheel type governor for constant speed service at higher speeds. Many illustrations show details of construction and application to various drive arrangements. Specifications, dimension sheets and general engineering data are included. 24 pages, 8½ x 11—Troy Engine and Machine Company, Troy, Pa.

Welded Pipe for Gas Lines

Bulletin No. 510 is a particularly comprehensive discussion of the design and construction of gas lines with welded pipe. First, an imposing array of charts and calculations is presented to show how the most economical proportions for a pipe line are determined. This study maintains a happy balance between engineering and economics. The second section illustrates and describes numerous applications. The photographs are interesting and are well reproduced. A chapter on general engineering data pertaining to SMITH Welded Pipe concludes the booklet. All of the information is well presented and this bulletin will be of value to any engineer who is interested in either pipe lines or welded piping. 52 pages and cover, 8½ x 11—A. O. Smith Corporation, Milwaukee, Wis.

NOTICE

Manufacturers are requested to send copies of their new catalogs and bulletins for review on this page. Address copies of your new literature to

COMBUSTION

200 Madison Ave., New York

REVIEW OF NEW TECHNICAL BOOKS

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Principles of Engineering Thermodynamics

By Paul J. Kiefer and Milton C. Stuart

IN content, arrangement of matter and method of treatment, this book is something of a departure from standard texts on the subject. The authors have endeavored, and with considerable success, to clear up certain misconceptions such as that involved in the term "total heat" or "heat content" and to give the reader a better and more practical understanding of fundamentals. Entropy, for instance, is discussed at some length and, as J. H. Keenan comments on this section of the book in his review in the February 3, 1931 issue of "Power", ". . . . . in these chapters many engineers will doubtless find for the first time the common sense of entropy."

The general character of the treatment is indicated by the following summarization of the five Parts into which the work is divided. Part I considers the First Law of Thermodynamics, with particular emphasis on an understanding of the distinctive characteristics of the several stored and transient forms of energy and of the energy equation as it applies to the innumerable steady-flow machines which are encountered in engineering practice. Part II considers the Second Law and the Carnot Principle, with emphasis on the availability of energy and the associated physical significance of the entropy function as an index of the unavailability of energy. Part III describes the physical properties of the vapors and gases and their mixtures. Part IV utilizes the principles and methods of the preceding parts in analyses of motive-power machinery and certain power-using apparatus, with attention both to ideal performances and to the character and reasons for the departure of actual performances from the ideal. For those interested in the correlation of the physical properties of fluids or with the further applications of thermodynamics in physics and chemistry, Part V develops the General Thermodynamic Equations.

Means and methods for the utilization of heat energy have advanced so rapidly in recent years that a sound grasp of fundamentals has become a practical necessity. This book will be of great assistance to those who wish to acquire a thorough understanding of the principles of thermodynamics.

This book is 6½ by 9¼ overall and contains 545 pages. The price is $4.50.

Engineering Materials Vol. III

By Arthur W. Judge

THE present volume represents a thoroughly revised and extended account of that section of the author's "Aircraft and Automobile Materials, (Ferrous)," dealing with the theory and testing of materials.

An elementary account is given of the theory of strength properties of materials so as to enable the student, engineer, and user of materials in general, to appreciate the importance of material specifications, applications, and test methods.

In view of the increasing importance of a knowledge of the properties of materials under the action of varying stresses, a fairly full account has been given of the subject of Fatigue in metals.

A new section dealing with the properties of metals at the higher temperatures, based on the latest available information, has also been included.

Other new sections added include Hardness and Hardness Testing Machines, Abrasion and Wear Tests, the Testing of Cast Iron, Modern Theories of Materials, and Optical Methods of Stress Determination.

No attempt has been made to deal exhaustively with any one branch of the subject; the aim has been rather to give a connected general account for the engineering student, the engineer, designer, and others interested in the application of materials.

This book is 6 by 8½ overall and contains 500 pages. The price is $6.00.

The Engineers Vest Pocket Book

By W. A Thomas

THIS is a handy pocket size reference book which provides a wide variety of useful information for the engineer, principally in the form of tables, charts and formulas. It has 12 main divisions as follows: Mathematics; Statics and Dynamics; Strength of Materials; Building Construction; Mechanical Design; Heat; Hydraulics; Chemistry and Physics; Electrics; Transportation; Surveying; Costs and General.

This book contains 224 pages, size 2¾ by 5 3/8 overall, bound in flexible morocco leather. An extensive index and marginal captions facilitate quick reference. The price is $3.00.

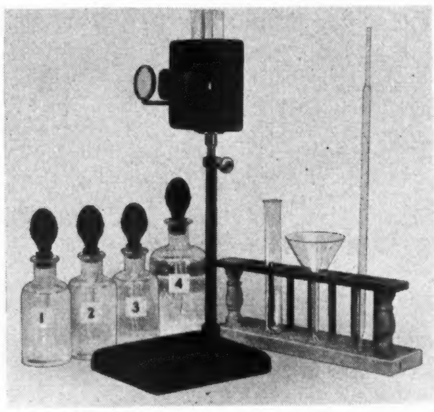
NEW EQUIPMENT

of interest to steam plant Engineers

Phosphate Comparator for Feed Water Determination

THE HAGAN CORPORATION, Combustion and Chemical Engineers, Pittsburgh, Pa., have announced the development of a simple and reliable method of phosphate determination in connection with boiler water conditioning. The apparatus has been so simplified that analyses may be made by the boiler operator with every assurance of quick and accurate results.

The reduced-phosphomolybdate photometric method which has been used during the past decade in biological work, is the simplest scheme now known for the determina-



tion of small amounts of phosphate. It is based on the fact that the yellow phosphomolybdate formed by the reaction in acid solution between an orthophosphate and molybdic acid is easily reduced to a deeply colored blue compound. The depth of blue color so produced becomes a measure of the phosphate present in a treated sample.

It is in the final comparison of the blue color with some standard that a difficulty as far as use of the method in the boiler room arises. In the chemical laboratory time and skill enable the chemist to prepare a set of blue standards from solutions containing known amounts of phosphate, and to determine the phosphate in the sample by comparison with these. The lack of time, skill and equipment makes such a procedure cumbersome to follow by the operator in the boiler room. Therefore, that this method be suitable for water conditioning work it is essential that the boiler operator have some ready means of carrying out this final comparison of the blue color, and hence of thus determining the phosphate in his samples.

Matching the blue color with a standard for comparison consisting of a dye in solution suffers from the disadvantage that the standard will fade in time. Fixed, permanent standards are the answer to the difficulty. Colored glass standards represent the ideal since they can be made to match the blue color given by the phosphate and are absolutely permanent as far as everything except mechanical breakage is concerned.

Suitable glass standards have been developed by Hellige-Klett, Inc., and incorporated in the apparatus illustrated in which comparisons can readily be made. The sample in a small glass cell is treated to develop the color and this cell is placed in one side of the comparator. In the other side in a similar cell is placed another portion of the sample. This compensates any color that the boiler water sample may have since the light passing through the blue glass standard also passes through it. Thus, no matter what kind or quantity of color the sample may have, so long as it is translucent, an accurate estimate of the phosphate it contains can be made with this device.

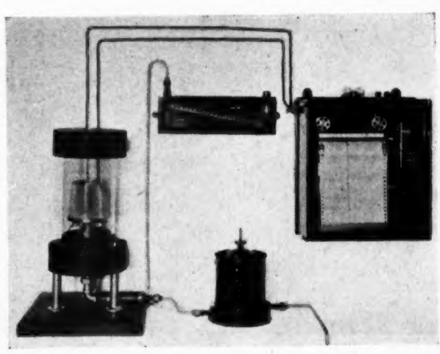
The Hellige glass standards have been incorporated in a compact comparator. The two beams of light entering the back of the comparator through a white glass plate, and passing, one through the treated portion of the sample, and the other through the compensating portion and colored glass standard, are brought into juxtaposition by a system of prisms. Because of their juxtaposition, the colors are readily and accurately matched by the observer. The entire outfit and procedure are such as to lend themselves admirably to use in the laboratory or in the boiler room by those either skilled or unskilled in chemical laboratory methods. Having the permanent glass color disc as the ultimate standard of measurement makes this method much more reliable than one depending on standard solutions, which are difficult to prepare and to preserve without deterioration.

The illustration shows equipment suitable for the analysis of any number of boiler waters. In addition to those shown, extra comparison cells may be secured in case it is desirable to make a number of determinations simultaneously.

The comparator is capable of being used not only with the recently developed phosphate color disc, but with color discs for pH determinations in case these are desired.

New Instrument Measures and Controls Heating Effect of Gases

A WIDELY useful instrument for checking the heating effect of fuel gas has been developed by The Brown Instrument Company, Philadelphia. The new instrument, which is called the Brown Flame Analyzer, can be supplied to measure, record and automatically control the heating effect of any gas. With this instrument gas companies, industrial



plants using producer gas, and the many new plants supplying butane gas to small communities, are enabled to check and regulate the quality of their gas output with special reference to the heating effect. In the many cases where it is necessary to dilute a rich gas, or enrich a lean gas, the flame analyzer equipment not only makes it easy to observe and record the quality of the output, but makes possible a dependable automatic control of the mixture that will insure a uniform product. The value of such a device is self-evident in numerous industries where gas fuel is largely employed, as well as being a boon to the manufactured gas field. To the latter it will be of great assistance providing gas of maximum utility to the consumer at minimum cost; especially since the gas analyzer is of direct assistance to the operator of the gas making machines.

In many industrial processes the Brown Gas Analyzer, particularly in its automatic control type, can materially aid production. There are a great number of cases in industry where the heating effectiveness of gas fuel is vital as in manufacturing processes where great sensitivity to changes in the rate of heat propagation exists. The Brown Flame Analyzer can be applied to the needs of such processes and, when connected to the necessary control equipment, will maintain a uniform pilot flame in the analyzer, which in turn will result in unvarying flames throughout the plant.

The accompanying illustration shows the Brown Flame Analyzer, together with the recording instrument and a pressure governor and gauge controlling the flow of gas through the analyzer.

This new Flame Analyzer, it will be readily seen, has a very broad field, applying to the needs of the gas companies, the large gas consumers, iron and steel plants where efficient utilization of immense volumes of coke oven gas and blast furnace gas is an important problem, and to special requirements in many fields and processes where gas is used.

A New Powercoater for Boiler Tubes

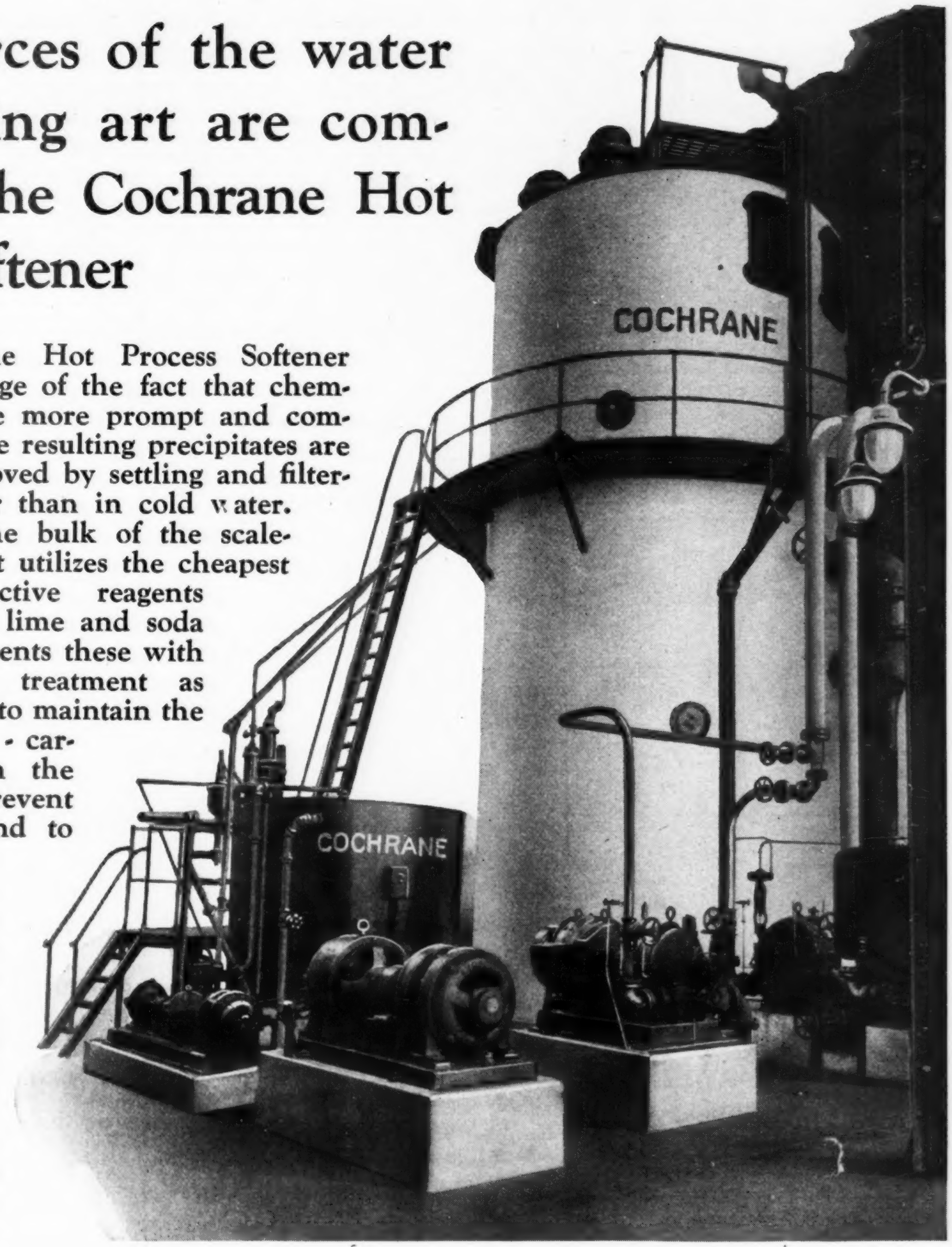
THE DAMPNEY COMPANY OF AMERICA, Hyde Park, Boston, Mass., has recently developed a new Powercoater, designated Style E, to be used in the application of APEXIOR, the Protective Coating, to the internal tube surfaces of water tube boilers. This new Powercoater is not only an improvement over previous models but is also less expensive. It is used as an attachment to the air driven, turbine type of boiler tube cleaner.

The Powercoater consists essentially of a circular base with means for attaching to the tube cleaner. In this base are mounted two short arms which, when in operation, open out into a V formation due to centrifugal force. Two removable bristle brushes with die cast backs are fastened to the ends of these arms by means of pins with split ends. The freedom of movement of the arms on the base end of the brushes on the arms, allows for the adjustment of the brushes to the inner surface of the tube as the Powercoater opens out in the tube due to the rotation of the tube cleaner.

The brushes pick up the liquid APEXIOR which has previously been deposited in the tube and thoroughly brush and scrub the coating into the surface of the metal. The APEXIOR thus forms a thin, smooth coating over the entire inner tube surface. This coating dries quickly and is impervious to any action of the hot water and steam in contact with it. In fact, the APEXIOR, while not retarding the flow of heat, serves as a protective coating between the metal and the water and steam so as to prevent any possibility of pitting and corrosion.

When coating straight tubes, the Powercoater is attached to the tube cleaner by a rigid coupling and for coating bent tubes, a universal type of coupling is used.

All resources of the water conditioning art are combined in the Cochrane Hot Process Softener



THE Cochrane Hot Process Softener takes advantage of the fact that chemical reactions are more prompt and complete and that the resulting precipitates are more easily removed by settling and filtering in hot water than in cold water. For removing the bulk of the scale-forming matter it utilizes the cheapest and most effective reagents known, namely, lime and soda ash, but supplements these with such corrective treatment as may be required to maintain the proper sulphate - carbonate ratios in the boiler water to prevent embrittlement and to secure complete protection against scale deposits, as, for example, by the use of phosphates according to the Hall System.

The Cochrane Hot Process Softener gives complete protection against corrosion by oxygen and by acid by deaerating the water and maintaining a suitable alkalinity.

The hot process softener fits in perfectly with varying steam plant conditions, utilizing exhaust steam, conserving condensed returns or serving as one of the stages of a regenerative feed heating system. It may include deaeration and metering of the feed water, as well as heating and softening.

Ask for the Cochrane Bulletins relating to water conditioning problems; one recently issued, IC-678 "Zero Hardness," compares the hot process with zeolites and other methods.

COCHRANE CORPORATION

3160 North 17th Street, Philadelphia, Pa.

F-5

Boiler, Stoker and Pulverized Fuel Equipment Sales

Total figures to January 1, as reported to the Department of Commerce by the leading manufacturers in each industry

Boiler Sales

	Total 12 mo. 1930		Total 12 mo. 1929		Dec., 1929		Dec., 1930	
	No.	Sq. ft.	No.	Sq. ft.	No.	Sq. ft.	No.	Sq. ft.
Water tube	1070	5,562,877	1650	9,409,526	66	278,587	32	130,438
H.R.T.	879	1,179,486	1366	1,830,028	77	100,991	23	28,373

Mechanical Stoker Sales

Year and Month	Total		Type of Boiler			
			Fire-tube		Water-tube	
	No.	HP.	No.	HP.	No.	HP.
1929						
Total (year)	1,716	599,585	706	102,515	1,010	497,070
1930						
January	53	13,198	24	2,872	29	10,326
February	73	22,648	26	3,732	47	18,916
March	89	32,403	45	6,128	44	26,275
April	108	35,903	46	6,984	62	28,919
May	96	31,956	41	5,703	55	26,253
June	151	47,803	70	10,100	81	37,703
July	150	37,761	83	11,434	67	26,327
August	115	29,988	61	10,587	54	19,401
September	128	42,899	71	9,186	57	33,713
October	92	38,276	46	5,148	46	33,128
November	71	21,103	41	5,731	30	15,372
December	53	11,726	35	5,307	18	6,419
Total (Year)	1,179	365,664	589	82,912	590	282,752

Pulverized Fuel Equipment Sales

Year and Month	Central System			Unit System		
	No. of Pulverizers	Total Rated capacity in tons of coal per hour	Total Rated hp. of boilers equipped	No. of Pulverizers	Total Rated capacity in tons of coal per hour	Total Rated hp. of boilers equipped
1930	For Installation Under Water-Tube Boilers					
January	1	6	1,600	52	565	59,742
February	2	20	3,000	29	175	23,305
March	2	50	6,414	16	33	9,995
April	....	....	....	*39	*153	*38,931
May	3	80	11,360	30	196	22,625
June	1	6	802	15	28	7,146
July	2	22	1000	12	29	20,424
August	....	....	....	4	13	1,454
September	....	....	....	24	112	18,729
October	....	....	....	10	16	3,499
November	....	....	....	15	40	7,692
December	....	....	....	3	5	958
Total (Year)	11	184	24,176	249	1,365	214,500
	For Installation Under Fire-Tube Boilers					
January	....	....	....	6	35	965
February	....	....	....	2	13	305
March	....	....	....	3	3	450
April	....	....	....	3	3	780
May	....	....	....	....	....	....
June	....	....	....	....	....	....
July	....	....	....	....	....	....
August	....	....	....	3	3	712
September	....	....	....	6	3	900
October	....	....	....	....	....	....
November	....	....	....	5	3	641
December	....	....	....	....	....	....
Total (Year)	....	....	....	28	63	4,753

*Revised